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MANNED SPACECRAFT CENTER
HOUSTON, TEXAS
PRELIMINARY DESIGN COLUMBIUM
COMBUSTOR TEST REPORT
Report S-595
April 4, 1967
NASA Contract: NAS 9-6003

III. INTRODUCTION

The Preliminary Design Columbiu Combustor Test is a part of a program to develop a coated, columbiu combustion chamber for application with the TMC Apollo S/M RCS engine. In conjunction with the engine testing portion of the program, various other activities are also being undertaken. These activities include metallurgical studies of the combustor material/coating system, combustor structural and thermal analysis and configuration management studies for incorporation of the part into the Apollo S/M RCS engines. Following these efforts, firing tests will be conducted with the final chamber configuration. The results of the preliminary design combustor firing test will be presented in this report.

The Preliminary Design Columbiu Combustor Test was conducted to demonstrate the thermal and structural adequacy of the combustor design and the associated seal and attach ring design while operating in the steady state and pulse modes under conditions similar to those required of the qualified Apollo S/M RCS combustor.

Two combustors were utilized in this test. Both combustors were subjected to a nearly identical test program which consisted of a Continuous Run Test, Pulse Operation Survey Test and an Ignition Test (see Figure 1). The details of each test are set forth in the test plan, Reference 1. The data acquired for each test will be presented individually for each combustor in the text of this report. Performance and thermal data acquired from the Apollo S/M RCS Engine Qualification and Supplemental Qualification Tests (see References 3 and 2, respectively) were included in applicable sections of this report for comparison with the data obtained from the Preliminary Design Columbiu Combustor Test.

IV DISCUSSION

This Test was Performed under
NASA Contract: NAS 9-6003

PRELIMINARY DESIGN COLUMBIUM
COMBUSTOR TEST REPORT

Report S-595
April 4, 1967

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COMBUSTOR TEST REPORT

APRIL 4, 1967

Written by



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Approved by



D. C. Sund



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REFERENCES

1. MTN 3448, Test Plan, Columbium Alloy Combustion Chamber Development Program - Preliminary Design Chamber Tests; dated 1 September 1966, revised 10 October 1966;

as modified by:

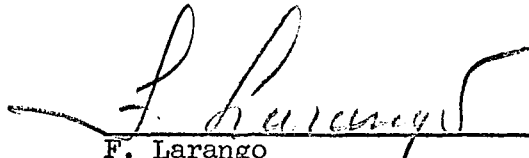
TMC Letter 3024/153-41/5568; Corrections - Marquardt Test Plan MTN 3448; dated 25 January 1967

TMC Letter 3024/153-41/5728; Addendum - Marquardt Test Plan MTN 3448; dated 14 March 1967

2. TMC Report A 1068, R-4D Supplemental Qualification Test Report for the Apollo S/M RCS Engine, dated 7 December 1966.
3. TMC Report A 1057, Qualification Test Report for Apollo S/M RCS Engine, dated 17 January 1966.

STATEMENT OF QUALITY ASSURANCE

The tests described in this report were conducted under the surveillance of The Marquardt Corporation, Quality Assurance Department. Test procedures followed conformed to those mutually agreed upon by TMC and NASA-Houston.

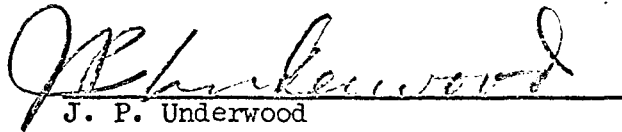


F. Larango
Chief Inspector, Quality Assurance
The Marquardt Corporation

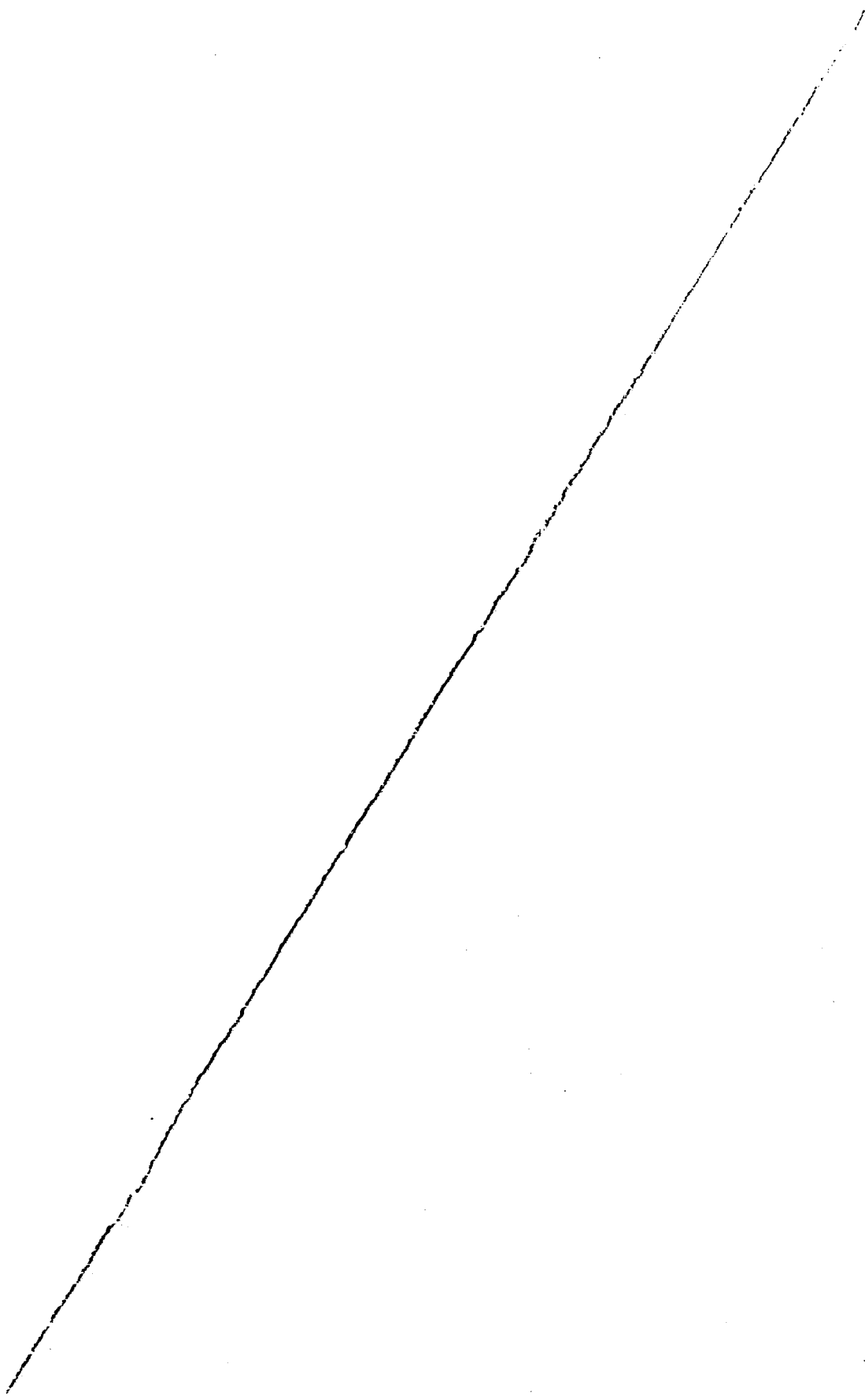


R. L. Lints
Manager, Quality Assurance
The Marquardt Corporation

Government source inspection was conducted in accordance with the letter of delegation for the Preliminary Design Columbiu Combustor Test as authorized by NASA prime contract NAS 9-6003.



J. P. Underwood
DCAS Representative



I. OBJECTIVE

The objective of this report is to present the results of the Preliminary Design Columbium Combustor Test in partial fulfillment of NASA Contract NAS 9-6003.

The purpose of the Preliminary Design Columbium Combustor Test was to demonstrate the acceptability and isolate the problem areas, if any, of a preliminary design C-103 columbium alloy combustor with a slurry applied silicide coating (Sylvania R-512A) and the associated combustor seal and attach ring design for application with the TMC Apollo S/M RCS engine.

II. SUMMARY

NGT-27309

Three tests were conducted with each of two combustors: a Continuous Run test, a Pulse Operation Survey test, and an Ignition test. Combustor No. 2 was subjected to the tests in the order stated, and combustor No. 1 underwent testing in reverse order. Both combustors accrued over 1,650 seconds of operation and 10,000 starts (see Figure 2) without exhibiting structural degradation or design deficiencies. Performance and thermal data acquired from the Continuous Run tests were compared to Apollo S/M RCS Qualification and Supplemental Qualification Test results obtained under similar conditions. This comparison showed that engine performance was unaffected by the use of a columbium combustor and that the injector head steady state and soakback temperatures of the columbium engine configuration were lower than that of the qualified Apollo S/M RCS engine injector head assembly. Both combustors underwent over 600 off-design ignitions (in the vertical-up firing position with saturated propellants), programmed to cause chamber overpressures, without incurring a measurable or observed structural degradation.

On the basis of the data generated, the design of the columbium combustor, with its associated attach hardware, is adequate and acceptable without change as the final configuration.

Author

III. INTRODUCTION

The Preliminary Design Columbiu Combustor Test is a part of a program to develop a coated, columbiu combustion chamber for application with the TMC Apollo S/M RCS engine. In conjunction with the engine testing portion of the program, various other activities are also being undertaken. These activities include metallurgical studies of the combustor material/coating system, combustor structural and thermal analysis and configuration management studies for incorporation of the part into the Apollo S/M RCS engines. Following these efforts, firing tests will be conducted with the final chamber configuration. The results of the preliminary design combustor firing test will be presented in this report.

The Preliminary Design Columbiu Combustor Test was conducted to demonstrate the thermal and structural adequacy of the combustor design and the associated seal and attach ring design while operating in the steady state and pulse modes under conditions similar to those required of the qualified Apollo S/M RCS combustor.

Two combustors were utilized in this test. Both combustors were subjected to a nearly identical test program which consisted of a Continuous Run Test, Pulse Operation Survey Test and an Ignition Test (see Figure 1). The details of each test are set forth in the test plan, Reference 1. The data acquired for each test will be presented individually for each combustor in the text of this report. Performance and thermal data acquired from the Apollo S/M RCS Engine Qualification and Supplemental Qualification Tests (see References 3 and 2, respectively) were included in applicable sections of this report for comparison with the data obtained from the Preliminary Design Columbiu Combustor Test.

PRELIMINARY DESIGN COLUMBIUM COMBUSTOR

TEST MATRIX

Test	Combustor No. 2	Combustor No. 1
	P/N 228949 S/N 0002	P/N 228949 S/N 0003
Ignition	1	3
Pulse Operation Survey	2	2
Continuous Run	3	1

Notes:

Combustor No. 2 was tested with Engine P/N T-14100, S/N 0001-8 and S/N 0001-9

Combustor No. 1 was tested with Engine P/N T-14100, S/N 0001-10 and S/N 0001-11

The serial number of the engines used for the Ignition Tests were different because the standard Apollo exit bell was replaced by a P/N T-14767 test fixture.

FIGURE 1

IV DISCUSSION

IV. DISCUSSION

A. General

The Preliminary Design Columbium Combustor Test was conducted in two essentially identical parts. Both parts were conducted per NASA approved test plan MTN 3448 (Reference 1). The first part of the test was conducted between 2 November 1966 and 8 November 1966 with Engine P/N T-14100, S/N 0001-8 and 0001-9, which incorporated preliminary design combustor No. 2 (P/N 228949, S/N 0002). The propellants utilized for this part were monomethylhydrazine and nitric oxide inhibited nitrogen tetroxide (per MSC-PPD-2A). The propellants were fully helium saturated during the ignition testing and partially saturated for the remainder of the tests.

The Preliminary Design Columbium Chamber Test with combustor No. 2 was originally started on 18 October 1966 with Engine P/N T-14200, S/N 0001-12. After the fourteenth run of the Ignition Test, which was the first test scheduled, the test was terminated due to a detonation in the oxidizer manifold which damaged the oxidizer valve standoff and seat. The combustor was not damaged. An investigation of the incident was made. The results of that investigation are presented in Appendix I. The test was re-initiated with Engine P/N T-14100, S/N 0001-8.

The second part of the preliminary design test was conducted between 31 January 1967 and 8 February 1967 with Engine P/N T-14100, S/N 0001-10 and 0001-11 which incorporated preliminary design combustor No. 1 (P/N 228949, S/N 0003). Nitric oxide inhibited nitrogen tetroxide and Aerozine-50 were employed as the propellants for this part of the test. The steady state data acquired from this test are presented both in the "as taken" condition and corrected to standard Apollo conditions. Both propellants were fully helium saturated (see Section F, Method II).

As shown in Figure 1 of this report, both combustors were subjected to a Continuous Run Test, Pulse Operation Survey Test and an Ignition Test. Presented in Figure 2 are the burn time and number of altitude ignitions accrued on each combustor during each of the tests conducted.

TOTAL BURN TIME AND ALTITUDE
IGNITIONS ACCRUED FROM THE PRELIMINARY
DESIGN COLLECTOR COMBUSTOR TEST

	ENGINE P/ N T-14100 S/N 0001-8 & 0001-9 COMBUSTOR #2		ENGINE P/N T-14100 S/N 0001-10 & 0001-11 COMBUSTOR # 1	
	Total Altitude Ignitions	Total Burn Time sec.	Total Altitude Ignitions	Total Burn Time sec.
CONTINUOUS RUN	3	510.0	4	610.0
PULSE OPERATION SURVEY	9763	1137.84	9667	1128.78
IGNITION TEST	706 *	9.20 **	608	7.6
TOTALS	10,472*	1,656.04**	10,279	1746.38

* THIS NUMBER INCLUDES 103 STARTS ON ENGINE P/N T-14200, S/N 0001-12
WITH COMBUSTOR No. 2.

** THIS NUMBER INCLUDES 1.85 SEC OF BURN TIME ACCURED ON ENGINE P/N T-14200,
S/N 0001-12 WITH COMBUSTOR No. 2.

FIGURE 2

B. Continuous Run Test Results

The objectives of the Continuous Run test were to demonstrate engine performance and the thermal and structural adequacy of the columbium combustor and associated attach hardware when subjected to a long steady state run at nominal Apollo conditions.

The Continuous Run test, which was conducted per MTN 3448, Section V-A as amended by Deviation Sheet No. 10, consisted of conducting one 500-second run with combustor No. 2 and two runs, one of 400 seconds duration and the other of 200 seconds, with combustor No. 1.

Both combustors successfully completed the test under the conditions specified, with no indication of design deficiencies. No structural degradation was observed or measured, no engine performance degradation was measured, and the thermal characteristics of the columbium combustor were compatible with the Apollo S/M RCS engine.

Presented in Figure 3 is a tabulation of the steady state performance data obtained from the 500-second run with combustor No. 2 (Engine P/N T-14100, S/N 0001-9). This run was conducted with MMH as the fuel and nitric oxide inhibited N_2O_4 as the oxidizer; both propellants were partially helium saturated per Section F, Method I of this report. The performance data are presented in the "as taken" condition, except for thrust and specific impulse, which were corrected to total vacuum ($P_{cell} = 0$). Specific impulse, thrust and mixture ratio (O/F) taken directly from the Figure 3 tabulation are plotted against run time in Figure 4. As shown, the specific impulse was 278.5 seconds at a mixture ratio of 2.10. For this run, the average propellant temperature was 51°F. Figure 5 presents the data from the two trim runs associated with the 500-second run.

The uncorrected performance data acquired from the 500-second run (run number 4316) of the Apollo S/M RCS Engine Supplemental Qualification Test (Reference 2) conducted under similar conditions, but with standard Apollo hardware, is presented in Figure 6. This performance data was taken at an average mixture ratio of about 2.05 and propellant temperature of 61°F; hence, a direct comparison with the columbium combustor data cannot be made. However, by compiling all applicable data from the Apollo S/M RCS Engine Supplemental Qualification Program and the MMH Design Verification Program, three curves relating the specific impulse to mixture ratio and propellant temperature were made. These three curves: specific impulse as a function of mixture ratio; specific impulse as a function of average propellant temperature; and mixture ratio versus average propellant temperature are presented in Figures 7, 8 and 9, respectively. Using these three relationships, the specific impulse calculated from the columbium combustor

500-second run was corrected to the mixture ratio and propellant temperature of the supplemental qualification 500-second run. A comparative plot of the corrected columbium specific impulse and the supplemental qualification specific impulse versus run time is shown in Figure 10. The performance is identical.

Shown in Figures 11 and 12, respectively, are the steady state performance data taken from the 400-second and 200-second runs with combustor No. 1 (Engine P/N T-14100, S/N 0001-10). These two runs were conducted with fully helium saturated Aerozine-50 and N_2O_4 propellants. The saturation procedure used is set forth in Section F, Method II of this report. A plot of test condition specific impulse, thrust and mixture ratio versus run time for the two runs is depicted in Figure 13. Data tabulated from the 5-second trim runs associated with the 400 and 200-second runs are shown in Figures 14 and 15, respectively.

Figures 16 and 17, respectively, show the 400 and 200-second run performance data corrected to standard Apollo S/M RCS acceptance test conditions. Performance data, corrected to standard acceptance test conditions, acquired from a 500-second run (run number 1356) of the Apollo S/M RCS Qualification Test, which was conducted under conditions similar to the 400 and 200-second runs, is presented in Figure 18. Figure 19 compares the I_{sp} performance of the two engine configurations. The performance was slightly higher with the columbium configuration; however, this difference is attributable primarily to instrumentation accuracy tolerances and normal data scatter.

The thermal characteristics measured during the Continuous Run tests with the two columbium combustors are presented in Figures 20 through 22. For ease in comparing the thermal characteristics of the columbium combustor engines to the standard Apollo S/M RCS engine, Figures 23 and 24 were included.

Plotted in Figure 20 are the injector head, combustor flange and bell nut temperatures as a function of run time for the 500-second run with combustor No. 2. As noted on Figure 20, the maximum injector head and combustor flange soakback temperatures were 250°F and 312°F, respectively. Because of an apparent thermoscope malfunction, a record of the throat temperature was not obtained; however, since other temperatures recorded were similar to previously acquired data this run was not repeated.

Plotted in Figure 23 are the injector head, fuel insert, bell nut and throat temperatures measured during the Orbit Retrograde Test (run number 4316) of the Apollo Supplemental Qualification Test. This test was conducted with MMH fuel as was the test on columbium combustor No. 2. A comparison of Figures 20 and 23 shows that the injector head and bell nut

temperatures from the two engine configurations were essentially identical. Soakback temperatures were not recorded during the Supplemental Qualification Program; however from previous test experience at similar temperatures, the expected head and chamber flange soakback temperatures were probably about 315°F and 350°F, respectively. The combustor throat temperature, as measured during the Supplemental Qualification Test, was about 1950°F.

The head, combustor flange, bell nut and throat temperatures measured from the 400-second and 200-second runs conducted with combustor No. 1 are shown in Figures 21 and 22, respectively. Also shown in Figures 21 and 22 are the maximum head and flange soakback temperatures. In both cases, the maximum head soakback temperature was 260°F and the maximum flange soakback temperature was approximately 315°F. The throat temperatures for these two runs were about 2250°F. Chamber temperature distributions during these tests were also recorded with thermal sensitive, XR, film. These films are being analyzed for inclusion in the Final Thermal Analysis Report.

Plotted in Figure 24 are the various engine temperatures measured during run number 1356 (500-second run) of the Apollo S/M RCS Engine Qualification Test conducted with Aerozine-50 fuel. A comparison of Figures 21, 22 and 24, as expected, shows the columbium engine head and nut temperatures to be similar to the corresponding qualification engine temperatures during the burn test. The columbium engine flange and head soakback temperatures were 315°F and 255°F, respectively. Typical flange and injector head soakback temperatures measured from Apollo S/M RCS production configuration engines are 450°F and 320°F, respectively. The throat temperature of the columbium combustor was about 180°F warmer than that of the Qualification engine. This difference is slightly greater than predicted by the preliminary thermal analysis. The final thermal analysis will be corrected in accordance with these test data.

STEADY STATE TEST DATA

100 # THRUST ENGINE COLUMBIUM CHAMBER No. 2

PAGE 1 OF 2

S/N 0001-9

T-14100

ENGINE ASSEMBLY

11-8-66

TEST DATE

1

CELL NO.

3448

TEST NO.

APPENDIX PARAGRAPH

3448 V-A2

M.T.P.

INPUT	RUN NO.	TIME	\dot{w}_o cps	T_{fo} °F	\dot{w}_f cps	T_{fmf} °F	F_{test} -lbs	P_{CELL} -PSIA	P_{CTEST} -PSIA	P_{m_o} PSIA SET	P_{m_o} PSIA INLET	P_{mf} PSIA SET	P_{mf} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o TEST -pps	\dot{w}_f TEST -pps	\dot{w}_p TEST -pps	O/F TEST	F_{vac} TEST -lbs	I_{sp} TEST -sec	$C_{f,vac}$ TEST	C* TEST ft-sec	ΔP_o psi	ΔP_f psi	
	4515	5	1309.	55.4	997.	58.6	98.7	.0780	95.5	191.1	170.0	179.9	169.5
	1.4630	.8301	.2449	.1159	.3608	2.114	100.5	278.6	1.779	5039.	74.5	74.0	
	4515	100	1292.	51.1	992.	50.9	97.9	.0852	94.4	191.1	168.9	179.9	168.7
	1.4685	.8841	.2426	.1158	.3584	2.095	99.3	278.7	1.789	5013.	74.5	74.3	
	4515	200	1290.	51.2	992.	51.0	97.7	.0848	94.1	191.1	168.2	179.9	168.6
	1.4684	.8340	.2423	.1158	.3581	2.093	99.7	278.3	1.791	5000.	74.1	74.5	
	4515	300	1292.	51.4	992.	51.2	97.7	.0852	94.1	191.1	169.0	179.9	168.6
	1.4681	.8829	.2426	.1153	.3584	2.095	99.7	279.1	1.791	4997.	74.9	74.5	



STEADY STATE TEST DATA

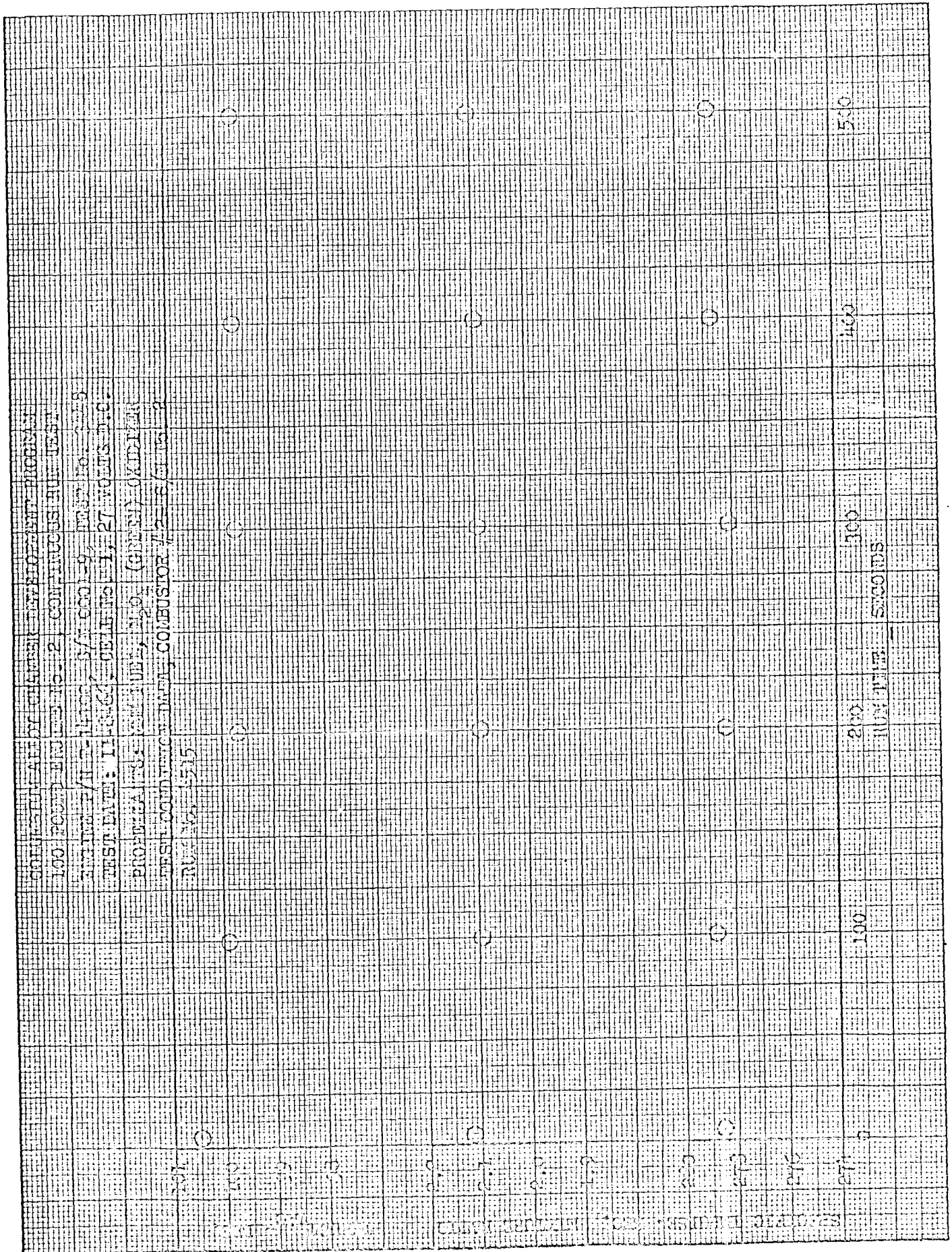
ENGINE ASSEMBLY T-14100 S/N 0001-9 PAGE 2 OF 2
TEST NO. 3448 CELL NO. 1 TEST DATE 11-8-66
M.T.P. 3448 V-A2 APPENDIX PARAGRAPH 1

INPUT	RUN NO.	TIME	\dot{w}_o cps	T_{fo} °F	\dot{w}_f cps	T_{fm} °F	F_{test} - lbs	P_{CELL} - PSIA	$P_{C TEST}$ - PSIA	P_{m_o} PSIA SET	P_{m_o} PSIA INLET	P_{m_f} PSIA SET	P_{m_f} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o TEST - pps	\dot{w}_f TEST - pps	\dot{w}_p TEST - pps	O/F TEST	$F_{vac TEST}$ - lbs	$I_{sp, vac TEST}$ - sec	C_f $C_{f, vac TEST}$	$C^* TEST$ ft-sec	ΔP_o psi	ΔP_f psi	
	4515	4.60	1290.	51.7	989.	51.4	97.7	.0852	94.1	191.1	168.7	179.9	168.6
	1.4676	.8338	.2422	.1154	.3576	2.099	99.7	278.7	1.791	5007.	74.6	74.5	
	4515	5.00	1292.	52.0	988.	51.8	97.7	.0852	94.1	191.1	169.2	179.9	168.1
	1.4673	.8335	.2424	.1152	.3576	2.105	99.7	278.7	1.791	5007.	75.1	74.0	

PREPARED BY LGW
 CHECKED BY AKI



PAGE _____
 DATE 2-15-67





THE
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CORPORATION

S-595

STEADY STATE TEST DATA

100 # THRUST ENGINE COLUMBIUM CHAMBER No. 2

T-14100

ENGINE ASSEMBLY

PAGE 1 OF 1

S/N 0001-9

TEST DATE 11-8-66

CELL NO. 1

3448

TEST NO.

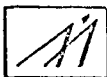
TRIM RUNS

APPENDIX PARAGRAPH

3448 V-A2

M.T.P.

INPUT	RUN NO.	TIME	\dot{w}_o cfs	T_{fo} °F	\dot{w}_f cfs	T_{fm} °F	F_{test} - lbs	P_{cell} - PSIA	$P_{c TEST}$ - PSIA	P_{m_o} PSIA SET	P_{m_o} PSIA INLET	P_{m_f} PSIA SET	P_{m_f} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o TEST - pps	\dot{w}_f TEST - pps	\dot{w}_p TEST - pps	O/F TEST	$F_{vac TEST}$ - lbs	$I_{sp, vac TEST}$ - sec	C_f vac TEST	$C^* TEST$ ft-sec	ΔP_o psi	ΔP_f psi	
	4513	5	1208.	55.4	991.	58.2	98.6	.0851	95.2	191.4	170.0	179.4	169.1
	1.4630	.2803	.2446	.1151	.3597	2.125	100.5	279.5	1.786	5036.	74.8	73.9	
	4514	5	1201.	50.9	994.	55.0	98.9	.0855	95.5	190.9	169.8	179.8	169.6
	1.4637	.2820	.2444	.1157	.3601	2.112	100.9	280.2	1.786	5049.	74.3	74.1	



THE
MARQUARDT
CORPORATION

SUPPLEMENTAL QUALIFICATION ENGINE # 3
(AMBIENT) ORBIT RETROGRADE TEST
STEADY STATE TEST DATA
(FUEL-MMH) (OX-N₂O₄"GREEN")

S-595

ENGINE ASSEMBLY 228686-501 S/N 0234 PAGE 1 OF 5
TEST NO. 3438 CELL NO. 1 TEST DATE 10-20-66
M.T.P. 0056 SEQ # 12 APPENDIX PARAGRAPH C-4.2

INPUT	RUN NO.	TIME	\dot{w}_o -cps	T_{fo} -°F	\dot{w}_f -cps	T_{fm} -°F	F_{test} -lbs	P_{CELL} -PSIA	P_{cTEST} -PSIA	P_{mo} PSIA SET	P_{mo} PSIA INLET	P_{mf} PSIA SET	P_{mf} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o TEST -pps	\dot{w}_f TEST -pps	O/F TEST	$F_{vacTEST}$ -lbs	$I_{spvacTEST}$ -sec	$C_{f vacTEST}$	$C_{f TEST}$ ft-sec	ΔP_o psi	ΔP_o psi	ΔP_f psi	
	4316	5	1311.	60.4	1114.	62.7	99.7	.0808	96.8	191.1	168.8	179.0	168.0
	1.4568	.8783	.2421	.1177	.3598	2.057	101.6	282.3	1.774	5120.	72.0	71.2	
	4316	30	1303.	58.4	1112.	56.7	98.9	.0876	95.8	191.1	168.1	179.0	167.6
	1.4593	.8814	.2409	.1179	.3588	2.043	100.9	281.3	1.781	5081.	72.3	71.8	
	4316	60	1306.	58.5	1114.	60.8	99.0	.0884	95.6	191.1	168.5	179.0	167.8
	1.4592	.8793	.2415	.1178	.3593	2.050	101.1	281.3	1.788	5062.	72.9	72.2	
	4316	90	1311.	60.9	1114.	61.7	99.0	.0884	95.7	191.1	168.2	179.0	167.7
	1.4561	.8788	.2420	.1178	.3598	2.055	101.1	281.0	1.786	5063.	72.5	72.0	

SUPPLEMENTAL QUALIFICATION ENGINE # 3
(AMBIENT) ORBIT RETROGRADE TEST
STEADY STATE TEST DATA
(FUEL-MMH) (OX-N₂O₄ "GREEN")

8-595

ENGINE ASSEMBLY 228686-501 S/N 0234 PAGE 2 OF 5
TEST NO. 3438 CELL NO. 1 TEST DATE 10-20-66
M.T.P. 0056 SEQ # 12 APPENDIX PARAGRAPH C-4.2

INPUT	RUN NO.	TIME	\dot{w}_o cps	T_{fo} °F	\dot{w}_f cps	O/F_{TEST}	$F_{vocTEST}$ - lbs	$I_{sp vocTEST}$ - sec	P_{CELL} - PSIA	P_{cTEST} - PSIA	P_{m_o} PSIA SET	P_{m_i} PSIA INLET	P_{m_i} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o - pps	\dot{w}_f - pps	\dot{w}_p - pps	O/F_{TEST}	$F_{vocTEST}$ - lbs	$I_{sp vocTEST}$ - sec	$C_{f vocTEST}$	C^*_{TEST} ft-sec	ΔP_o psi	ΔP_i psi	
	4316 120	1311. 61.5	1114. 62.1	99.0	.0884	95.7	191.1	168.3	179.0	167.6			
	1.4554 .8786	.2418 .1177	.3595 2.054	101.1	281.1	1.786	5065.	72.6	71.9				
	4316 150	1311. 61.8	1114. 62.6	99.0	.0884	95.6	191.1	168.5	179.0	167.6			
	1.4550 .8784	.2418 .1177	.3595 2.054	101.1	281.2	1.788	5060.	72.9	72.0				
	4316 180	1311. 62.0	1114. 62.6	99.0	.0884	95.7	191.1	168.3	179.0	167.6			
	1.4548 .8783	.2417 .1177	.3594 2.054	101.1	281.2	1.786	5067.	72.6	71.9				
	4316 210	1311. 62.1	1114. 62.9	99.0	.0884	95.6	191.1	168.2	179.0	167.7			
	1.4547 .8782	.2416 .1177	.3593 2.053	101.1	281.4	1.788	5063.	72.6	72.1				

SUPPLEMENTAL QUALIFICATION ENGINE # 3
(AMBIENT) ORBIT RETROGRADE TEST
STEADY STATE TEST DATA
(FUEL-MMH) (OX-N₂O₄ "GREEN")

S-595

ENGINE ASSEMBLY 228686-501 S/N 0234 PAGE 3 OF 5
TEST NO. 3438 CELL NO. 1 TEST DATE 10-20-66
M.T.P. 0056 SEQ # 12 APPENDIX PARAGRAPH C-4.2

INPUT	RUN NO.	TIME	SG _f	W _o TEST -pps	T _{fm} °F	W _f cps	O/F TEST	W _p TEST -pps	T _{fm} °F	F _{vac} TEST -lbs	I _{sp} vac TEST -sec	P _{cell} -PSIA	P _c TEST -PSIA	P _m SET	P _m PSIA INLET	P _m SET	P _m PSIA INLET
OUTPUT	SG _o																ΔP _f -psi
	4316	240		1311.	62.3	1115.	63.0	99.0	.0884	95.9	191.1	168.5	179.0	167.7			
	1.4544	.8781		.2417	.1178	.3595	2.051	101.1	281.1	1.782	5077.	72.6	71.8				
	4316	270		1309.	62.5	1115.	63.2	99.0	.0884	95.7	191.1	168.4	179.0	167.7			
	1.4541	.8780		.2413	.1178	.3591	2.048	101.1	281.4	1.786	5071.	72.7	72.0				
	4316	300		1309.	62.6	1114.	63.4	99.0	.0884	95.7	191.1	168.4	179.0	167.9			
	1.4539	.8779		.2413	.1176	.3589	2.051	101.1	281.6	1.786	5074.	72.7	72.2				
	4316	330		1309.	62.9	1114.	63.5	99.0	.0884	95.6	191.1	168.4	179.0	167.8			
	1.4536	.8779		.2412	.1176	.3588	2.051	101.1	281.6	1.788	5069.	72.8	72.2				



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SUPPLEMENTAL QUALIFICATION ENGINE # 3
(AMBIENT) ORBIT RETROGRADE TEST
STEADY STATE TEST DATA
(FUEL-MMH) (OX-N₂O₄ "GREEN")

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ENGINE ASSEMBLY 228686-501 S/N 0234 PAGE 4 OF 5
TEST NO. 3438 CELL NO. 1 TEST DATE 10-20-66

M.T.P. 0056 SEQ # 12 APPENDIX PARAGRAPH C-4.2

INPUT	RUN NO.	TIME	\dot{w}_o cps	T_{fo} °F	\dot{w}_f cps	T_{fm} °F	F_{test} -lbs	P_{CELL} -PSIA	$P_{C TEST}$ -PSIA	P_{m_o} PSIA SET	P_{m_o} PSIA INLET	P_{m_f} PSIA SET	P_{m_f} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o TEST -pps	\dot{w}_f TEST -pps	\dot{w}_f TEST -pps	O/F TEST	$F_{vac TEST}$ -lbs	$I_{sp vac TEST}$ -sec	$C_f vac TEST$	$C^* TEST$ ft-sec	ΔP_o psi	ΔP_f psi	
	4316	360	1309.	62.9	1115.	63.6	99.0	.0884	95.6	191.1	168.2	179.0	167.7
	1.4535	.8778	.2412	.1178	.3590	2.048	101.1	281.5	1.788	5067.	72.6	72.1	
	4316	390	1309.	63.0	1115.	63.8	99.0	.0884	95.8	191.1	168.1	179.0	167.8
	1.4534	.8777	.2412	.1178	.3590	2.048	101.1	281.5	1.784	5079.	72.3	72.0	
	4316	420	1309.	63.1	1114.	63.9	98.9	.0880	95.5	191.1	168.2	179.0	167.7
	1.4533	.8777	.2412	.1176	.3588	2.051	100.9	281.4	1.788	5064.	72.7	72.2	
	4316	450	1308.	63.3	1114.	64.0	98.9	.0880	95.5	191.1	168.4	179.0	167.6
	1.4530	.8776	.2408	.1176	.3584	2.048	100.9	281.7	1.788	5069.	72.9	72.1	



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SUPPLEMENTAL QUALIFICATION ENGINE # 3
(AMBIENT) ORBIT RETROGRADE TEST
STEADY STATE TEST DATA
(FUEL- MMH) (OX-N₂O₄ "GREEN")

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ENGINE ASSEMBLY 228686-501 S/N 0234 PAGE 5 OF 5
TEST NO. 3438 CELL NO. 1 TEST DATE 10-20-66
M.T.P. 0056 SEQ # 12 APPENDIX PARAGRAPH C-4.2

INPUT	RUN NO.	TIME	\dot{w}_o cps	T_{fo} °F	\dot{w}_f cps	T_{fmf} °F	F_{test} lbs	P_{CELL} - PSIA	P_{cTEST} - PSIA	P_{m_o} PSIA SET	P_{m_o} PSIA INLET	P_{mf} PSIA SET	P_{mf} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o TEST -pps	\dot{w}_f TEST -pps	\dot{w}_p TEST -pps	O/F TEST	$F_{vacTEST}$ - lbs	$I_{sp,vacTEST}$ - sec	C_f vacTEST	C* TEST ft-sec	ΔP_o psi	ΔP_f psi	
	4316	480	1309.	63.3	1114.	64.2	98.9	.0884	95.7	191.1	168.1	179.0	167.4
	1.4530	.8775	.2411	.1176	.3587	2.051	101.0	281.4	1.784	5077.	72.4	71.7	
	4316	504	1311.	63.4	1112.	64.3	98.8	.0884	95.5	191.1	168.4	179.0	167.4
	1.4529	.8774	.2414	.1174	.3588	2.056	100.8	281.0	1.786	5064.	72.9	71.9	

ENGINE P/N T-14200, S/N 0001-7

12/7/50

REGRESSION LINE

MMH TEST PROGRAM

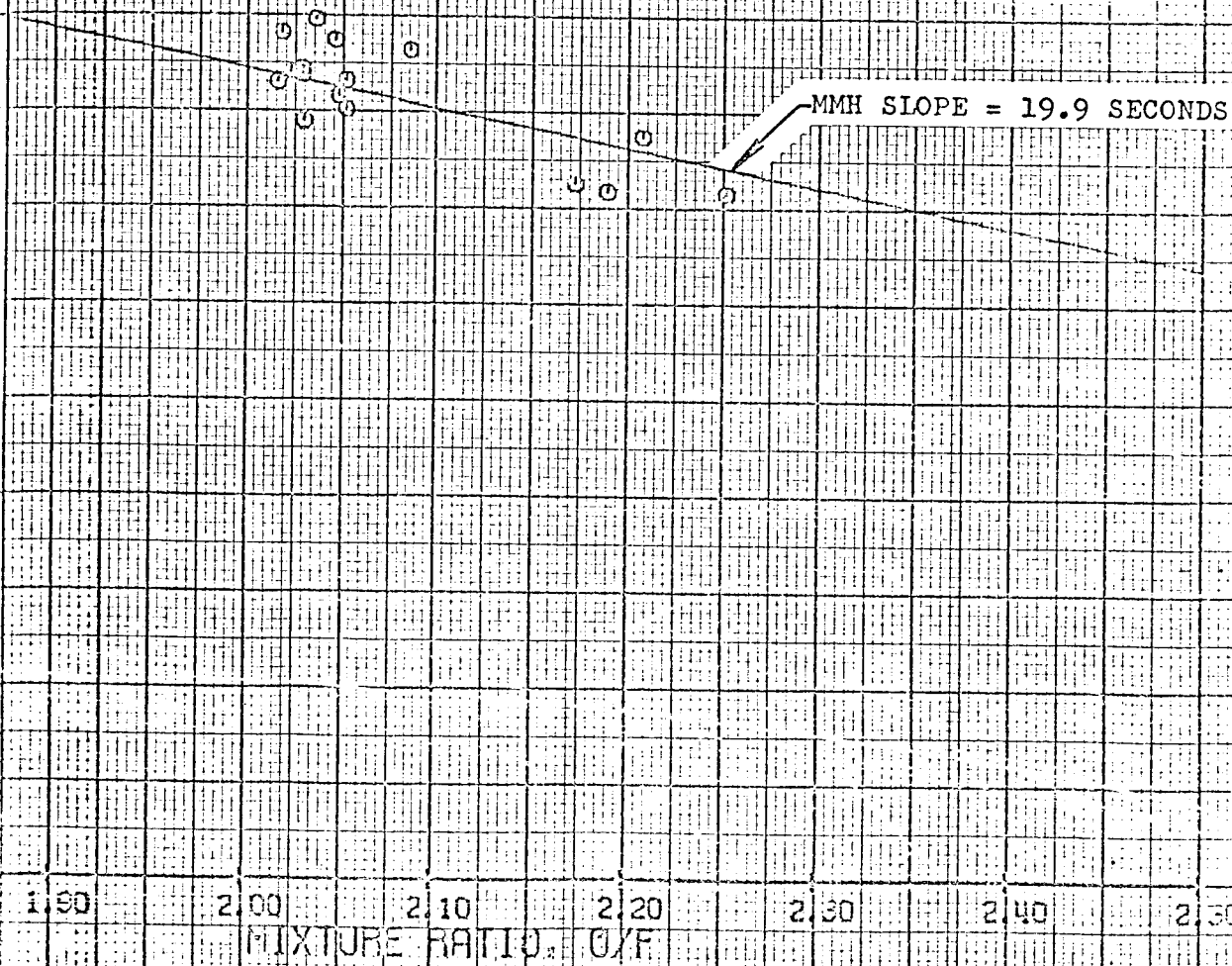
SPECIFIC IMPULSE VS. C/F

19.9 SECONDS

PROPELLANT TEMPERATURE RANGE:

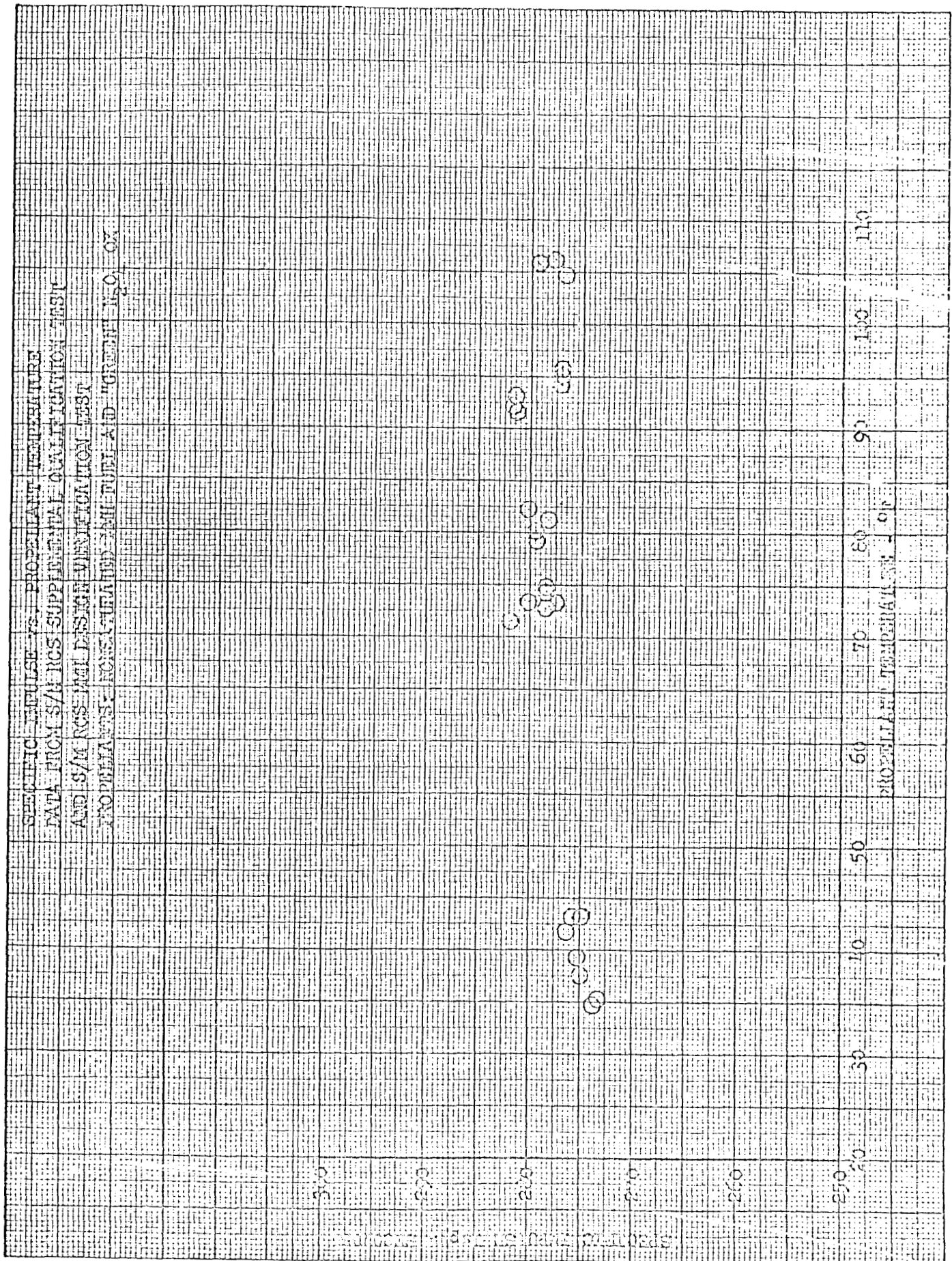
FUEL 70-77°F

OX 63-73°F



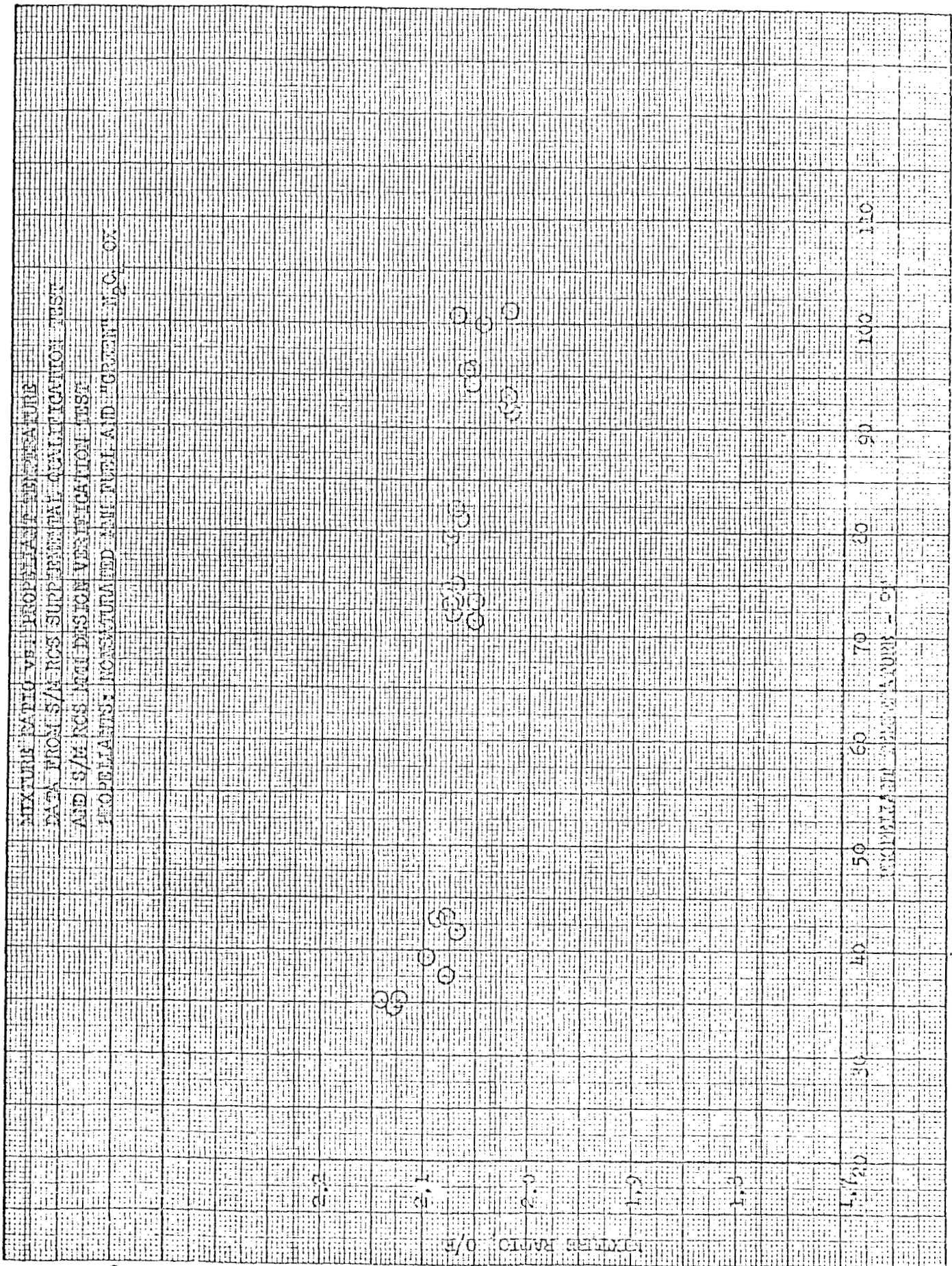
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DATE 2-15-67



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DATE 2-15-67





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STEADY STATE TEST DATA

ENGINE ASSEMBLY T-14199

COMBUSTION CHAMBER DEVELOPM

PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS

S/N 0001-10 PAGE 1 OF 4

TEST NO. 3448 COMBUSTOR NO. 1 CELL NO. 1 TEST DATE 1-31-67

M.T.P. MTN 3448 APPENDIX PARAGRAPH V.A.2 (CONTINUOUS RUN)

INPUT	RUN NO.	TIME	\dot{w}_o cps	T_{fo} °F	\dot{w}_f cps	T_{fm} °F	F_{vac} - lbs	F_{test} - lbs	P_{CELL} - PSIA	P_{cTEST} - PSIA	P_{m_o} PSIA SET	P_{m_o} PSIA INLET	P_{m_f} PSIA SET	P_{m_f} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o TEST - pps	\dot{w}_f TEST - pps	\dot{w}_p TEST - pps	O/F TEST	F_{vac} TEST - lbs	I_{sp} vac TEST - sec	$C_{f vac}$ TEST - sec	$C_{f vac}$ TEST	$C^* TEST$ ft-sec	ΔP_o - psi	ΔP_f - psi	
	4997	5	1266.	76.1	1005.	78.9	98.0	.0790	95.1	183.6	171.5	176.4	170.4	
	1.4376	.8954	.2404	.1184	.3588	2.031	99.8	278.3	1.775	5045.	76.4	75.3		
	4997	30	1267.	76.2	1008.	79.3	97.9	.0867	94.8	183.6	171.5	176.4	170.3	
	1.4375	.8952	.2407	.1187	.3594	2.027	99.9	278.0	1.782	5019.	76.7	75.5		
	4997	60	1267.	76.1	1008.	79.4	97.8	.0871	94.8	183.6	171.4	176.4	170.3	
	1.4376	.8951	.2407	.1187	.3594	2.027	99.8	277.7	1.781	5018.	76.6	75.5		
	4997	90	1267.	75.9	1008.	79.5	97.8	.0871	94.8	183.6	171.3	176.4	170.3	
	1.4379	.8951	.2407	.1187	.3594	2.028	99.8	277.7	1.781	5018.	76.5	75.5		

STEADY STATE TEST DATA

COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPI 1 PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS

ENGINE ASSEMBLY T-14100 S/N 001-10 PAGE 2 OF 4

TEST NO. 3448 COMBUSTOR No. 1 CELL NO. 1 TEST DATE 1-31-67

M.T.P. MTN 3448 APPENDIX PARAGRAPH V.A.2 (CONTINUOUS RUN)

INPUT	RUN NO.	TIME	\dot{w}_o cps	T_{fo} °F	\dot{w}_f cps	T_{fmf} °F	F_{test} -lbs	P_{CELL} -PSIA	P_{cTEST} -PSIA	P_{m_o} PSIA SET	P_{m_o} PSIA INLET	P_{m_f} PSIA SET	P_{m_f} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_{oTEST} -pps	\dot{w}_{fTEST} -pps	\dot{w}_{pTEST} -pps	O/F TEST	$F_{vacTEST}$ -lbs	$I_{spvacTEST}$ -sec	$C_{fvacTEST}$	C_{TEST} ft-sec	ΔP_o psi	ΔP_f psi	
	4997 120		1269.	75.9	1006.	79.5	97.8	.0871	94.8	183.6	171.3	176.4	170.2
	1.4379 .8951		.2410 .1185	.3595	2.033	99.8	277.6	1.781	5016.	76.5	75.4		
	4997 150		1269.	75.8	1006.	79.5	97.7	.0867	94.8	183.6	171.3	176.4	170.1
	1.4380 .8951		.2410 .1185	.3595	2.034	99.7	277.3	1.778	5016.	76.5	75.3		
	4997 180		1270.	75.6	1006.	79.6	97.7	.0867	94.7	183.6	171.2	176.4	170.0
	1.4382 .8951		.2414 .1185	.3599	2.037	99.7	277.0	1.780	5006.	76.5	75.3		
	4997 210		1270.	75.5	1006.	79.6	97.7	.0867	94.7	183.6	171.1	176.4	170.0
	1.4384 .8950		.2414 .1185	.3599	2.037	99.7	277.0	1.780	5005.	76.4	75.3		

STEADY STATE TEST DATA

ENGINE ASSEMBLY T-14100 S/N 001-10 COMBUSTOR NO. 1 CELL NO. 1 TEST DATE 1-31-67 PAGE 3 OF 4

M.T.P. MTN 3448 APPENDIX PARAGRAPH V.A.2. (CONTINUOUS RUN)

INPUT	RUN NO.	TIME	\dot{w}_o -cps	T_{fm} -°F	\dot{w}_f -cps	T_{fm} -°F	F_{vac} -lbs	F_{test} -lbs	P_{CELL} -PSIA	$P_{C TEST}$ -PSIA	P_{m_o} PSIA SET	P_{m_o} PSIA INLET	P_{m_f} PSIA SET	P_{m_f} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o TEST -pps	\dot{w}_f TEST -pps	\dot{w}_p TEST -pps	O/F TEST	F_{vac} TEST -lbs	F_{vac} TEST -lbs	$I_{sp, vac}$ TEST -sec	C_f TEST -sec	$C^* TEST$ ft-sec	ΔP_o psi	ΔP_f psi	
	4997	240	1260.	75.5	1006.	79.7	97.7	97.7	.0867	94.6	183.6	170.6	176.4	169.9
	1.4384	.8950	.2405	.1185	.3590	2.029	99.7	99.7	277.7	1.783	5012.	76.0	75.3	
	4997	270	1200.	75.5	1006.	79.7	97.6	97.6	.0867	94.6	183.6	170.5	176.4	170.0
	1.4384	.8950	.2405	.1185	.3590	2.029	99.6	99.6	277.4	1.781	5012.	75.9	75.4	
	4997	300	1200.	75.5	1006.	79.7	97.4	97.4	.0867	94.5	183.6	170.5	176.4	169.9
	1.4384	.8950	.2405	.1185	.3590	2.029	99.5	99.5	277.1	1.781	5006.	76.0	75.4	
	4997	330	1204.	75.5	1006.	79.7	97.6	97.6	.0867	94.5	183.6	170.4	176.4	169.8
	1.4384	.8950	.2402	.1185	.3587	2.027	99.6	99.6	277.6	1.783	5011.	75.9	75.3	



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STEADY STATE TEST DATA

ENGINE ASSEMBLY T-14100

COMBUSTION CHAMBER DEVELOPMENT

PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS

S/N 001-10

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OF 4

TEST NO. 3448

COMBUSTOR No. 1

TEST DATE 1-31-67

CELL NO. 1

M.T.P. MTN 3448

APPENDIX PARAGRAPH V.A.2. (CONTINUOUS RUN)

INPUT	RUN NO.	TIME	\dot{w}_o cps	T_{fo} °F	\dot{w}_f cps	T_{fm} °F	F_{vac} -lbs	F_{test} -lbs	P_{CELL} -PSIA	P_{cTEST} -PSIA	P_{mo} PSIA SET	P_{mo} PSIA INLET	P_{mf} PSIA SET	P_{mf} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o TEST -pps	\dot{w}_f TEST -pps	\dot{w}_p TEST -pps	O/F TEST	F_{vac} TEST -lbs	I_{sp} TEST -sec	$C_{f,vac}$ TEST -sec	$C_{f,vac}$ TEST -sec	C^*_{TEST} ft-sec	ΔP_o psi	ΔP_f psi	
	4997	360	1266.	75.5	1006.	79.7	97.7	.0867	94.5	183.6	170.3	176.4	169.7	
	1.4384	.8950	.2405	.1185	.3590	2.029	99.7	277.7	1.785	5006.	75.8	75.2		
	4997	390	1266.	75.4	1006.	79.7	97.7	.0867	94.5	183.6	170.1	176.4	169.6	
	1.4385	.8950	.2405	.1185	.3590	2.029	99.7	277.7	1.785	5006.	75.6	75.1		
	4997	400	1266.	75.3	1006.	79.7	97.7	.0867	94.5	183.6	170.1	176.4	169.5	
	1.4386	.8950	.2405	.1185	.3590	2.030	99.7	277.7	1.785	5006.	75.6	75.0		

STEADY STATE TEST DATA

COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS

ENGINE ASSEMBLY T-14100

S/N 001-10

COMBUSTOR No. 1

TEST NO. 3448

CELL NO. 1

TEST DATE 2-1-67

TEST DATE 2-1-67

Y.A.2. (CONTINUOUS RUN)

APPENDIX PARAGRAPH

M.T.P. MTN 3448

INPUT	RUN NO.	TIME	\dot{w}_o cps	T_{fm} °F	\dot{w}_f cps	T_{fm} °F	F_{vac} - lbs	F_{rest} - lbs	P_{CELL} - PSIA	P_{C-TEST} - PSIA	P_{m_o} PSIA SET	P_{m_o} PSIA INLET	P_{m_f} PSIA SET	P_{m_f} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o TEST -pps	\dot{w}_f TEST -pps	\dot{w}_p TEST -pps	O/F TEST	F_{vac} TEST - lbs	I_{sp} vac TEST - sec	$C_{f,vac}$ TEST	$C_{f,vac}$ TEST	C^*_{TEST} ft-sec	ΔP_o - psi	ΔP_f - psi	
	4999	5	1270.	77.6	1004.	78.7	98.3	.0812	95.1	183.7	171.7	176.4	170.5	
	1.4357	.8955	.2409	.1143	.3592	2.036	100.2	279.0	1.783	5035.	76.6	75.4		
	4999	30	1273.	77.7	1006.	80.0	98.6	.0884	94.6	183.7	171.4	176.4	170.4	
	1.4355	.8948	.2415	.1184	.3599	2.039	100.6	279.6	1.798	5002.	76.8	75.8		
	4999	60	1273.	77.7	1006.	80.0	98.0	.0888	94.7	183.7	171.4	176.4	170.4	
	1.4356	.8948	.2415	.1184	.3599	2.039	100.1	278.0	1.786	5008.	76.7	75.7		
	4999	90	1272.	77.7	1006.	80.0	97.5	.0888	94.7	183.7	171.3	176.4	170.4	
	1.4356	.8948	.2412	.1184	.3596	2.036	99.5	276.7	1.777	5012.	76.6	75.7		

STEADY STATE TEST DATA

COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS

ENGINE ASSEMBLY T-14100 S/N 001-10 PAGE 2 OF 2

TEST NO. 3448 COMBUSTOR NO. 1 TEST DATE 2-1-67

M.T.P. MTN 3448 APPENDIX PARAGRAPH V.A.2. (CONTINUOUS RUN)

INPUT	RUN NO.	TIME	\dot{w}_o cgs	T_{fo} °F	\dot{w}_f cgs	T_{fm} °F	F_{test} -lbs	P_{CELL} -PSIA	P_{CTEST} -PSIA	P_{m_o} PSIA SET	P_{m_o} PSIA INLET	P_{m_f} PSIA SET	P_{m_f} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o TEST -pps	\dot{w}_f TEST -pps	\dot{w}_p TEST -pps	O/F TEST	F_{vac} TEST -lbs	I_{sp} TEST -sec	C_f TEST -sec	C^* TEST ft-sec	ΔP_o psi	ΔP_f psi	
	4999	120	1272.	77.4	1006.	80.1	97.7	.0888	94.7	183.7	171.3	176.4	170.4
	1.4359	.8948	.2413	.1184	.3597	2.037	99.8	277.3	1.780	5011.	76.6	75.7	
	4999	150	1272.	77.3	1008.	80.1	97.5	.0888	94.7	183.7	171.3	176.4	170.4
	1.4360	.8948	.2413	.1186	.3599	2.034	99.5	276.5	1.777	5008.	76.6	75.7	
	4999	180	1272.	77.3	1008.	80.1	97.6	.0888	94.7	183.7	171.3	176.4	170.4
	1.4361	.8948	.2413	.1186	.3599	2.034	99.6	276.8	1.778	5008.	76.6	75.7	
	4999	200	1272.	76.9	1008.	80.1	97.6	.0888	94.7	183.7	171.2	176.4	170.4
	1.4365	.8948	.2414	.1186	.3600	2.034	99.6	276.8	1.778	5007.	76.5	75.7	

STEADY STATE TEST DATA

COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPMENT I

RAM-PRELIMINARY DESIGN CHAMBER TESTS

ENGINE ASSEMBLY T 14100 S/N 0001-10 PAGE 1 OF 1
COMBUSTOR No 1 CELL NO. 1 TEST DATE 1-31-67

M.T.P. MTN 3448 APPENDIX PARAGRAPH V.A.-1 (TURBINE TRIM)

INPUT	RUN NO.	TIME	\dot{w}_o cps	T_{fo} °F	\dot{w}_f cps	T_{fm} °F	F_{test} - lbs	P_{CELL} - PSIA	$P_{C TEST}$ - PSIA	P_{m_o} PSIA SET	P_{m_o} PSIA INLET	P_{m_f} PSIA SET	P_{m_f} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_o TEST -pps	\dot{w}_f TEST -pps	\dot{w}_p TEST -pps	O/F TEST	F_{vac} TEST - lbs	I_{sp} TEST - sec	$C_{f, vac}$ TEST	C^*_{TEST} ft-sec	ΔP_o psi	ΔP_f psi	
	4996	5	1272.	76.1	1006.	79.3	98.7	.0798	95.6	184.3	172.2	176.8	170.6
	1.4376	.8952	.2416	.1185	.3601	2.038	100.5	279.2	1.779	5049.	76.6	75.0	



STEADY STATE TEST DATA

COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOP. : PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS

ENGINE ASSEMBLY T-14100 S/N 001-10 PAGE 1 OF 1
COMBUSTOR No 1 CELL NO. 1 TEST DATE 2-1-67

M.T.P. MTN 3448 APPENDIX PARAGRAPH V.A.1. (TURBINE TRIM RUN)

INPUT	RUN NO.	TIME	\dot{w}_o cps	T_{fo} °F	\dot{w}_f cps	T_{fm} °F	F_{test} -lbs	P_{CELL} -PSIA	P_{cTEST} -PSIA	P_{m_o} PSIA SET	P_{m_o} PSIA INLET	P_{m_f} PSIA SET	P_{m_f} PSIA INLET
OUTPUT	SG _o	SG _f	\dot{w}_{oTEST} -pps	\dot{w}_{fTEST} -pps	\dot{w}_{pTEST} -pps	O/FTEST	$F_{vacTEST}$ -lbs	$I_{spvacTEST}$ -sec	$C_{fvacTEST}$	C^*_{TEST} ft-sec	ΔP_o psi	ΔP_f psi	
	4998	5	1273.	76.5	1004.	77.7	98.0	.0816	95.5	183.6	171.6	176.3	170.3
	1.4370	.8960	.2417	.1184	.3501	2.042	99.9	277.4	1.769	5046.	76.1	74.8	



STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

S-595

STANDARD CONDITIONS

$$P_{m_o} = P_{m_f} = 170 \text{ PSIA}$$

$$T_{fm_o} = T_{fm_f} \quad 75^{\circ}\text{F}$$

PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS

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001-10

S/N

00171-2

2000

COMBUSTOR No 1

COMBU:

TEST DATE 1-31-67

1-31-67

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1

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8772

2000

V.A.2. (CONTINUOUS RUN)

APPENDIX PARAGRAPH -

MAIN

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TEST DATA	RUN NO. SG _o	DATA STATION SG _f	P _{ch} TEST - PSIA	\dot{w}_f TEST - pps	\dot{w}_p TEST - pps	O/F TEST	I _{spvac} TEST - sec	C* TEST - ft/sec	ΔP_o - psi	ΔP_f - psi
CORRECTED TO STD. COND.	O/F _s	I _{spvac} - sec	\dot{w}_f - pps	\dot{w}_o - pps	\dot{w}_p - pps	F _{vac} - lbs	C* - ft/sec	P _{ch} - PSIA	C _f vac _s	
	4997	5								
	1.4376	.8954	95.1	.1184	.3588	2.031	278.3	5045.	76.4	75.3
	2.013	278.8	.1185	.2385	.3570	99.5	5052.	94.8	1.775	
	4997	30								
	1.4375	.8952	94.8	.1187	.3594	2.027	278.0	5019.	76.7	75.5
	2.008	278.5	.1189	.2388	.3577	99.6	5026.	94.5	1.783	
	4997	60								
	1.4376	.8951	94.8	.1187	.3594	2.027	277.7	5018.	76.6	75.5
	2.010	278.1	.1189	.2390	.3579	99.5	5025.	94.5	1.781	
	4997	90								
	1.4379	.8951	94.8	.1187	.3594	2.028	277.7	5018.	76.5	75.5
	2.011	278.1	.1189	.2391	.3580	99.5	5024.	94.5	1.781	
MEAN O/F _s			Δ O/F _s	MEAN F _{vac} - lbs.	Δ F _{vac} - lbs.	MEAN I _{spvac}	Δ I _{spvac}			



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STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

S-595

STANDARD CONDITIONS

$$P_{m_0} = P_{m_f} = 170 \text{ PSIA}$$

$$T_{fm_0} = T_{fm_f} = 75^\circ \text{F}$$

COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN TESTS

ENGINE ASSEMBLY T-14100 S/N 001-10 PAGE 2 OF 4

TEST NO. 3448 COMBUSTOR NO 1 CELL NO. 1 TEST DATE 1-31-67

M.T.P. MTN 3448 APPENDIX PARAGRAPH V.A.2. (CONTINUOUS RUN)

TEST DATA	RUN NO. SG ₀	DATA STATION SG _f	P _{ch} TEST - PSIA	w _f TEST - pps	w _p TEST - pps	O/F TEST	I _{sp} vac TEST - sec	C* TEST - ft/sec	ΔP ₀ - psi	ΔP _f - psi
CORRECTED TO STD. COND.	O/F _s	I _{sp} vac _s - sec	w _f - pps	w _o - pps	w _p - pps	F _{vac} - lbs	C* - ft/sec	P _{ch} - PSIA	C _f vac _s	
	4997	120								
	1.4379	.8951	94.5	.1185	.3595	2.033	277.6	5016.	76.5	75.4
	2.016	278.0	.1188	.2394	.3582	99.6	5023.	94.5	1.781	
	4997	150								
	1.4390	.8951	94.8	.1185	.3595	2.034	277.3	5016.	76.5	75.3
	2.014	277.8	.1188	.2393	.3581	99.5	5024.	94.6	1.779	
	4997	180								
	1.4382	.8951	94.7	.1185	.3599	2.037	277.0	5006.	76.5	75.3
	2.017	277.5	.1189	.2398	.3587	99.5	5014.	94.5	1.781	
	4997	210								
	1.4384	.8950	94.7	.1185	.3599	2.037	277.0	5005.	76.4	75.3
	2.019	277.4	.1188	.2399	.3587	99.5	5013.	94.5	1.781	
MEAN O/F _s	Δ O/F _s	MEAN F _{vac} - lbs.	Δ F _{vac} - lbs.	MEAN I _{sp} vac _s	Δ I _{sp} vac _s					

STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

8-595

STANDARD CONDITIONS

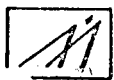
$$P_{m_0} = P_{m_f} = 170 \text{ PSIA}$$

$$T_{fm_0} = T_{fm_f} = 75^\circ\text{F}$$

ENGINE ASSEMBLY T-14100 S/N 001-10 PAGE 3 OF 4
COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS
TEST NO. 3448 COMBUSTOR No 1 CELL NO. 1 TEST DATE 1-31-67

M.T.P. MTN 3448 APPENDIX PARAGRAPH V.A.2. (CONTINUOUS RUN)

TEST DATA	RUN NO. SG ₀	DATA STATION SG _f	P _{ch} TEST - PSIA	w _f TEST - pps	w _P TEST - pps	O/F TEST	I _{sp} VAC TEST - sec	C* TEST - ft/sec	ΔP ₀ - psi	ΔP _f - psi
CORRECTED TO STD. COND.	O/F _s	I _{sp} VAC _s - sec	w _f _s - pps	w ₀ _s - pps	w _P _s - pps	F _{VAC} _s - lbs	C* _s - ft/sec	P _{ch} _s - PSIA	C _f VAC _s	
	4997	240								
	1.4384	.8950	94.6	.1185	.3590	2.029	277.7	5012.	76.0	75.3
	2.018	277.9	.1188	.2398	.3586	99.6	5015.	94.5	1.783	
	4997	270								
	1.4384	.8950	94.6	.1185	.3590	2.029	277.4	5012.	75.9	75.4
	2.020	277.4	.1188	.2400	.3588	99.5	5013.	94.5	1.781	
	4997	300								
	1.4384	.8950	94.5	.1185	.3590	2.029	277.1	5006.	76.0	75.4
	2.019	277.2	.1188	.2399	.3587	99.4	5008.	94.4	1.781	
	4997	330								
	1.4384	.8950	94.5	.1185	.3587	2.027	277.6	5011.	75.9	75.3
	2.016	277.7	.1189	.2397	.3586	99.6	5012.	94.5	1.783	
MEAN O/F _s		Δ O/F _s	MEAN F _{VAC} _s - lbs.	Δ F _{VAC} _s - lbs.	MEAN I _{sp} VAC _s	Δ I _{sp} VAC _s				



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STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

S-595

STANDARD CONDITIONS

$$P_{m_0} = P_{m_f} = 170 \text{ PSIA}$$

$$T_{f_{m_0}} = T_{f_{m_f}} = 75^\circ \text{F}$$

ENGINE ASSEMBLY T-14100

COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPM

PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS

S/N 001-10

PAGE 4 OF 4

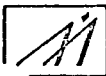
COMBUSTOR No 1

TEST DATE 1-31-67

M.T.P. MTW 3448

APPENDIX PARAGRAPH V.A.2. (CONTINUOUS RUN)

TEST DATA	RUN NO. SG ₀	DATA STATION SG _f	P _{ch} TEST - PSIA	\dot{w}_f TEST - pps	\dot{w}_p TEST - pps	O/F TEST	I _{sp} vac TEST - sec	C* TEST - ft/sec	ΔP_0 - psi	ΔP_f - psi
CORRECTED TO STD. COND.	O/F _s	I _{sp} vac _s - sec	\dot{w}_f - pps	\dot{w}_o - pps	\dot{w}_p - pps	F _{vac} - lbs	C* _s - ft/sec	P _{ch} - PSIA	C _f vac _s	
	4997	360								
	1.4384	.8950	94.5	.1185	.3590	2.029	277.7	5006.	75.8	75.2
	2.019	277.8	.1189	.2401	.3590	99.7	5008.	94.5	1.785	
	4997	390								
	1.4385	.8950	94.5	.1185	.3590	2.029	277.7	5006.	75.6	75.1
	2.020	277.7	.1190	.2403	.3593	99.8	5007.	94.5	1.785	
	4997	400								
	1.4386	.8950	94.5	.1185	.3590	2.030	277.7	5006.	75.6	75.0
	2.019	277.8	.1190	.2403	.3593	99.8	5008.	94.6	1.785	
MEAN O/F _s $\Delta O/F_s$ MEAN F _{vac} - lbs. $\Delta F_{vac} - lbs. MEAN Isp vacs \Delta I_{sp} vac_s$										



THE
MARQUARDT
CORPORATION

STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

S-595

STANDARD CONDITIONS

$$P_{m_0} = P_{m_f} = 170 \text{ PSIA}$$

$$T_{fm_0} = T_{fm_f} = 75^{\circ}\text{F}$$

COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS

ENGINE ASSEMBLY T-14100 S/N 001-10 PAGE 1 OF 2

TEST NO. 3448 COMBUSTOR NO 1 CELL NO. 1 TEST DATE 2-1-67

M.T.P. MTN 3448 APPENDIX PARAGRAPH V.A.2. (CONTINUOUS RUN)

TEST DATA	RUN NO. SG ₀	DATA STATION SG _f	P _{ch} TEST - PSIA	w _f TEST - pps	w _p TEST - pps	O/F TEST	I _{spvac} TEST - sec	C* TEST - ft/sec	ΔP ₀ - psi	ΔP _f - psi
CORRECTED TO STD. COND.	O/F _s	I _{spvac} - sec	w _f - pps	w _o - pps	w _p - pps	F _{vac} - lbs	C* - ft/sec	P _{ch} - PSIA	C _f vac _s	
	4499	5								
	1.4357	.8955	95.1	.1183	.3592	2.036	279.0	5035.	76.6	75.4
	2.020	275.3	.1184	.2391	.3575	99.9	5040.	94.7	1.783	
	4499	30								
	1.4355	.8948	94.6	.1184	.3599	2.039	279.6	5002.	76.8	75.8
	2.025	275.7	.1186	.2401	.3587	100.3	5004.	94.3	1.798	
	4499	60								
	1.4350	.8943	94.7	.1184	.3599	2.039	278.0	5008.	76.7	75.7
	2.025	278.2	.1186	.2401	.3587	99.8	5009.	94.4	1.787	
	4499	90								
	1.4356	.8948	94.7	.1184	.3596	2.036	276.7	5012.	76.6	75.7
	2.024	276.8	.1186	.2399	.3585	99.2	5013.	94.4	1.777	
MEAN O/F _s	Δ O/F _s	MEAN F _{vac} - lbs.	Δ F _{vac} - lbs.	MEAN I _{spvac}	Δ I _{spvac}					



THE
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STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

8-595

STANDARD CONDITIONS

$$P_{E_0} = P_{m_f} = 170 \text{ PSIA}$$

$$T_{fm_0} = T_{fm_f} = 75^{\circ}\text{F}$$

ENGINE ASSEMBLY T-14100 COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS
S/N 001-10 PAGE 2 OF 2

TEST NO. 3448 COMBUSTOR No 1 CELL NO. 1 TEST DATE 2-1-67

M.T.P. MTN 3448 APPENDIX PARAGRAPH V.A.2. (CONTINUOUS RUN)

TEST DATA	RUN NO. SG ₀	DATA STATION SG _f	P _{ch} TEST - PSIA	W _f TEST - pps	W _P TEST - pps	O/F TEST	I _{sp,vac} TEST - sec	C* TEST - ft/sec	ΔP ₀ - psi	ΔP _f - psi
CORRECTED TO STD. COND.	O/F _s	I _{sp,vac} - sec	W _f - pps	W _O - pps	W _P - pps	F _{vac} - lbs	C* - ft/sec	P _{ch} - PSIA	C _{f,vac} _s	
	4999	120								
	1.4359	.8948	94.7	.1184	.3597	2.037	277.3	5011.	76.6	75.7
	2.024	277.4	.1186	.2399	.3585	99.4	5012.	94.4	1.781	
	4999	150								
	1.4360	.8948	94.7	.1186	.3599	2.034	276.5	5008.	76.6	75.7
	2.021	276.6	.1187	.2399	.3586	99.2	5010.	94.4	1.777	
	4999	180								
	1.4361	.8948	94.7	.1186	.3599	2.034	276.8	5008.	76.6	75.7
	2.021	276.9	.1187	.2400	.3587	99.3	5010.	94.4	1.779	
	4999	200								
	1.4365	.8948	94.7	.1186	.3600	2.034	276.8	5007.	76.5	75.7
	2.022	276.9	.1187	.2401	.3588	99.4	5008.	94.5	1.779	
MEAN O/F _s	Δ O/F _s	MEAN F _{vac} - lbs.	Δ F _{vac} - lbs.	MEAN I _{sp,vac}	Δ I _{sp,vac}					

ENGINE ASSEMBLY 228687

S/N 0013

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QUALIFICATION ENGINE # 4

TEST NO. 3324

CELL NO. 1

TEST DATE 11-3-65

M.T.P. 0004A SEQUENCE # 17

APPENDIX PARAGRAPH L-5.1

TEST DATA	RUN NO. SG ₀	DATA STATION SG _f	P _{ch} TEST - PSIA	W _f TEST - pps	W _{P_s} TEST - pps	O/F TEST	I _{sp} VAC TEST - sec	C* TEST - ft/sec	ΔP ₀ - psi	ΔP _f - psi
CORRECTED TO STD. COND.	O/F _s	I _{sp} VAC _s - sec	W _{f_s} - pps	W _{O_s} - pps	W _{P_s} - pps	F _{VAC_s} - lbs	C* _s - ft/sec	P _{ch_s} - PSIA	C _f VAC _s	
	1356	5								
	1.4562	.9056	94.1	.1175	.3553	2.024	276.9	5039.	74.0	75.4
	2.038	278.0	.1171	.2387	.3558	98.9	5058.	94.6	1.768	
	1356	30								
	1.4587	.9061	93.4	.1177	.3559	2.024	274.9	4994.	74.6	75.8
	2.034	276.3	.1174	.2389	.3563	98.5	5020.	94.0	1.771	
	1356	60								
	1.4562	.9051	93.2	.1177	.3564	2.028	274.6	4976.	74.8	75.8
	2.036	275.9	.1176	.2395	.3571	98.5	4999.	93.8	1.776	
	1356	90								
	1.4549	.9046	93.3	.1177	.3560	2.025	275.4	4987.	74.5	75.4
	2.032	276.6	.1178	.2394	.3572	98.8	5008.	94.0	1.777	
MEAN O/F _s	ΔO/F _s	MEAN F _{VAC_s} - lbs.	ΔF _{VAC_s} - lbs.	MEAN I _{sp} VAC _s	ΔI _{sp} VAC _s					

STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

STANDARD CONDITIONS

 $P_{m_0} = P_{m_f} = 170 \text{ PSIA}$ $T_{m_0} = T_{m_f} = 75^\circ \text{F}$

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ENGINE ASSEMBLY 228687

S/N 0013

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TEST NO. 3324

QUALIFICATION ENGINE # 4

TEST DATE 11-3-65

M.T.P. 0004A

SEQUENCE # 17

APPENDIX PARAGRAPH

I-5.1

TEST DATA	RUN NO. SG ₀	DATA STATION SG _f	P _{ch} TEST - PSIA	\dot{w}_f TEST - pps	\dot{w}_p TEST - pps	O/F TEST	I _{spvac} TEST - sec	C* TEST - ft/sec	ΔP ₀ - psi	ΔP _f - psi
CORRECTED TO STD. COND.	O/F _s	I _{spvac} - sec	\dot{w}_f - pps	\dot{w}_o - pps	\dot{w}_p - pps	F _{vac} - lbs	C* - ft/sec	P _{ch} - PSIA	C _f vac _s	
	1356	120								
	1.4549	.9046	93.2	.1176	.3559	2.026	275.2	4983.	74.6	75.4
	2.032	276.4	.1178	.2393	.3571	98.7	5005.	93.9	1.777	
	1356	150								
	1.4549	.9046	93.3	.1175	.3558	2.028	274.8	4990.	74.3	75.2
	2.035	276.0	.1177	.2396	.3573	98.6	5011.	94.1	1.772	
	1356	180								
	1.4549	.9046	93.2	.1175	.3558	2.028	275.1	4984.	74.3	75.3
	2.036	276.2	.1177	.2397	.3574	98.7	5004.	94.0	1.776	
	1356	210								
	1.4549	.9046	93.0	.1175	.3553	2.024	275.5	4981.	74.5	75.1
	2.027	276.9	.1179	.2391	.3570	98.8	5005.	93.9	1.780	
MEAN O/F _s	ΔO/F _s	MEAN F _{vac} - lbs.	ΔF _{vac} - lbs.	MEAN I _{spvac}	ΔI _{spvac}					

THE MARQUARDT CORPORATION STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

S-595

STANDARD CONDITIONS

 $P_{E0} = P_{mf} = 170$ PSIA $T_{fm0} = T_{fmi}$ 75°F

STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

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STANDARD CONDITIONS

$$P_{m_0} = P_{m_f} = 170 \text{ PSIA}$$

$$T_{m_0} = T_{m_f} = 75^\circ\text{F}$$

ENGINE ASSEMBLY 228687 S/N 0013 PAGE 3 OF 5
 TEST NO. 3324 QUALIFICATION ENGINE # 4 TEST DATE 11-3-65
 M.T.P. 0004A SEQUENCE # 17 APPENDIX PARAGRAPH I-5.1

TEST DATA	RUN NO. SG	DATA STATION SG _f	P _{ch} TEST - PSIA	w _f TEST - pps	w _p TEST - pps	O/F TEST	I _{spvac} TEST - sec	C* TEST - ft/sec	ΔP _o - psi	ΔP _f - psi
CORRECTED TO STD. COND.	O/F _s	I _{spvac} - sec	w _f - pps	w _o - pps	w _p - pps	F _{vac} - lbs	C* - ft/sec	P _{ch} - PSIA	C _f vac _s	
	1356	240								
	1.4536	.9046	93.4	.1175	.3556	2.026	275.0	4998.	74.0	74.7
	2.031	276.2	.1180	.2396	.3575	98.7	5019.	94.3	1.770	
	1356	270								
	1.4536	.9036	93.2	.1174	.3552	2.026	275.6	4993.	74.2	74.9
	2.030	276.8	.1179	.2393	.3572	98.9	5014.	94.1	1.776	
	1356	300								
	1.4536	.9036	92.9	.1175	.3553	2.024	274.9	4975.	74.2	75.4
	2.035	275.8	.1179	.2398	.3577	98.6	4991.	93.8	1.778	
	1356	330								
	1.4536	.9036	93.0	.1174	.3550	2.024	274.6	4985.	74.1	75.5
	2.038	275.3	.1176	.2397	.3573	98.4	4998.	93.9	1.772	
MEAN O/F _s			Δ O/F _s	MEAN F _{vac} - lbs.	Δ F _{vac} - lbs.	MEAN I _{spvac}				

ENGINE ASSEMBLY 228687

S/N 0013

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TEST NO. 3324

QUALIFICATION ENGINE # 4

TEST DATE 11-3-65

M.T.P. 0004A

SEQUENCE # 17

APPENDIX PARAGRAPH

1.5.1

TEST DATA	RUN NO. SG ₀	DATA STATION SG _f	P _{ch} TEST - PSIA	\dot{w}_f TEST - pps	\dot{w}_o TEST - pps	\dot{w}_p TEST - pps	O/F TEST	I _{sp} vac TEST - sec	C* TEST - ft/sec	ΔP_o - psi	ΔP_f - psi
CORRECTED TO STD. COND.	O/F _s	I _{sp} vac _s - sec	\dot{w}_f - pps	\dot{w}_o - pps	\dot{w}_p - pps	F _{vac_s} - lbs	C* - ft/sec	P _{ch_s} - PSIA	C _f vac _s		
	1356	360									
	1.4536	.9036	92.9	.1174	.2400	.3577	98.5	4990.	4977.	74.1	75.5
	2.040	275.4	.1177	.2400	.3577	98.5	4990.	93.8	1.776		
	1356	390									
	1.4536	.9036	92.9	.1174	.3552	2.026	274.5	4977.	74.0	75.2	
	2.037	275.4	.1178	.2400	.3579	98.5	4993.	93.9	1.775		
	1356	420									
	1.4536	.9036	92.9	.1175	.3551	2.022	274.8	4978.	73.8	75.1	
	2.034	275.6	.1180	.2400	.3580	98.7	4992.	93.9	1.776		
	1356	450									
	1.4536	.9036	92.9	.1174	.3548	2.022	275.0	4982.	73.8	75.1	
	2.034	275.8	.1179	.2398	.3577	98.7	4996.	93.9	1.776		
MEAN O/F _s		$\Delta O/F_s$	MEAN F _{vac_s} - lbs.	ΔF_{vac_s} - lbs.	MEAN I _{sp} vac _s	ΔI_{spvac_s}					

THE
MARQUARDT
CORPORATIONSTEADY STATE TEST DATA
CORRECTED TO STANDARD CONDITIONS

8-595

STANDARD CONDITIONS

$$P_{E_0} = P_{mf} = 170 \text{ PSIA}$$

$$T_{fm_0} = T_{fm_f} 75^\circ \text{F}$$



THE
MARQUARDT
CORPORATION

STEADY STATE TEST DATA CORRECTED TO STANDARD CONDITIONS

S-595

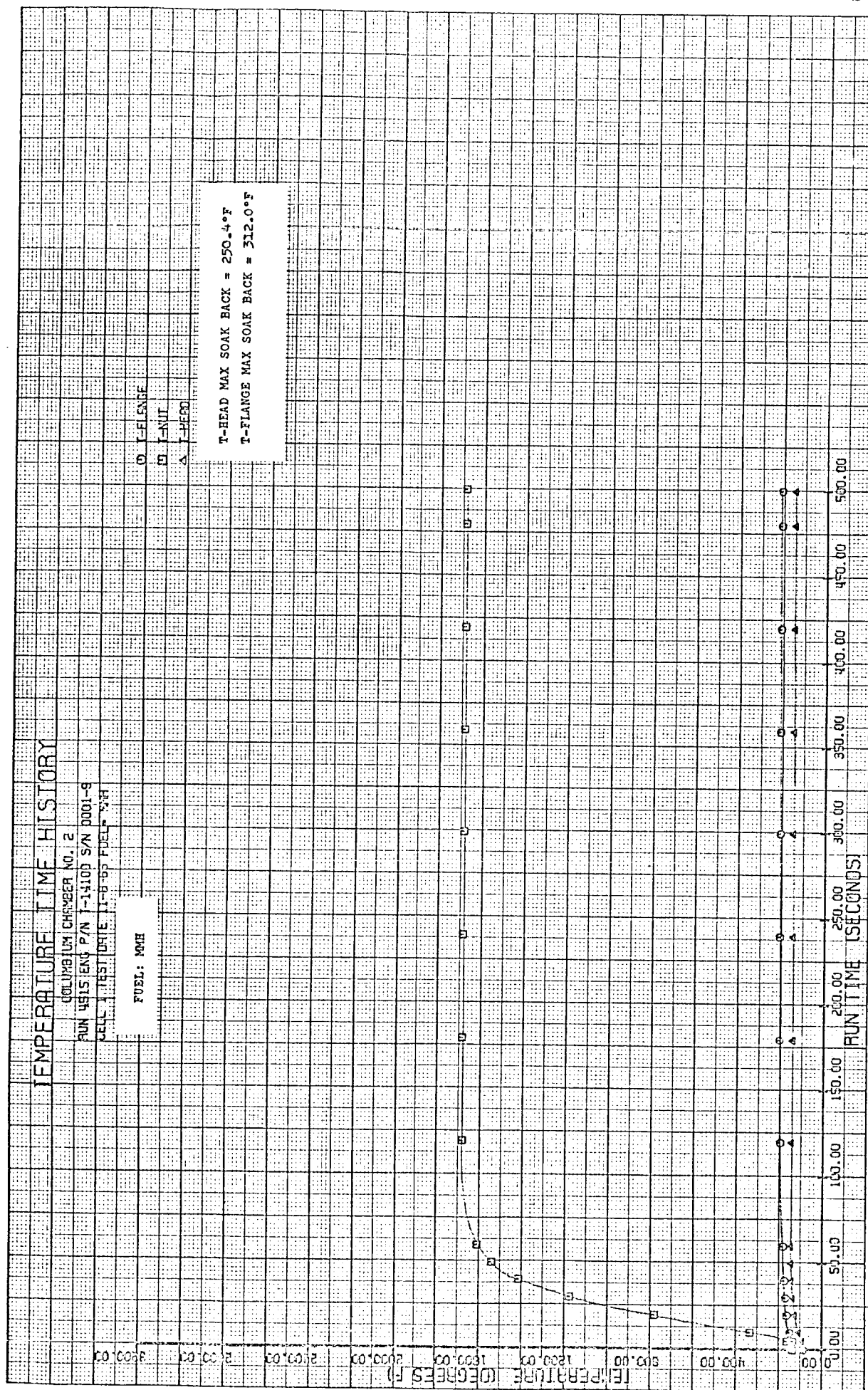
STANDARD CONDITIONS

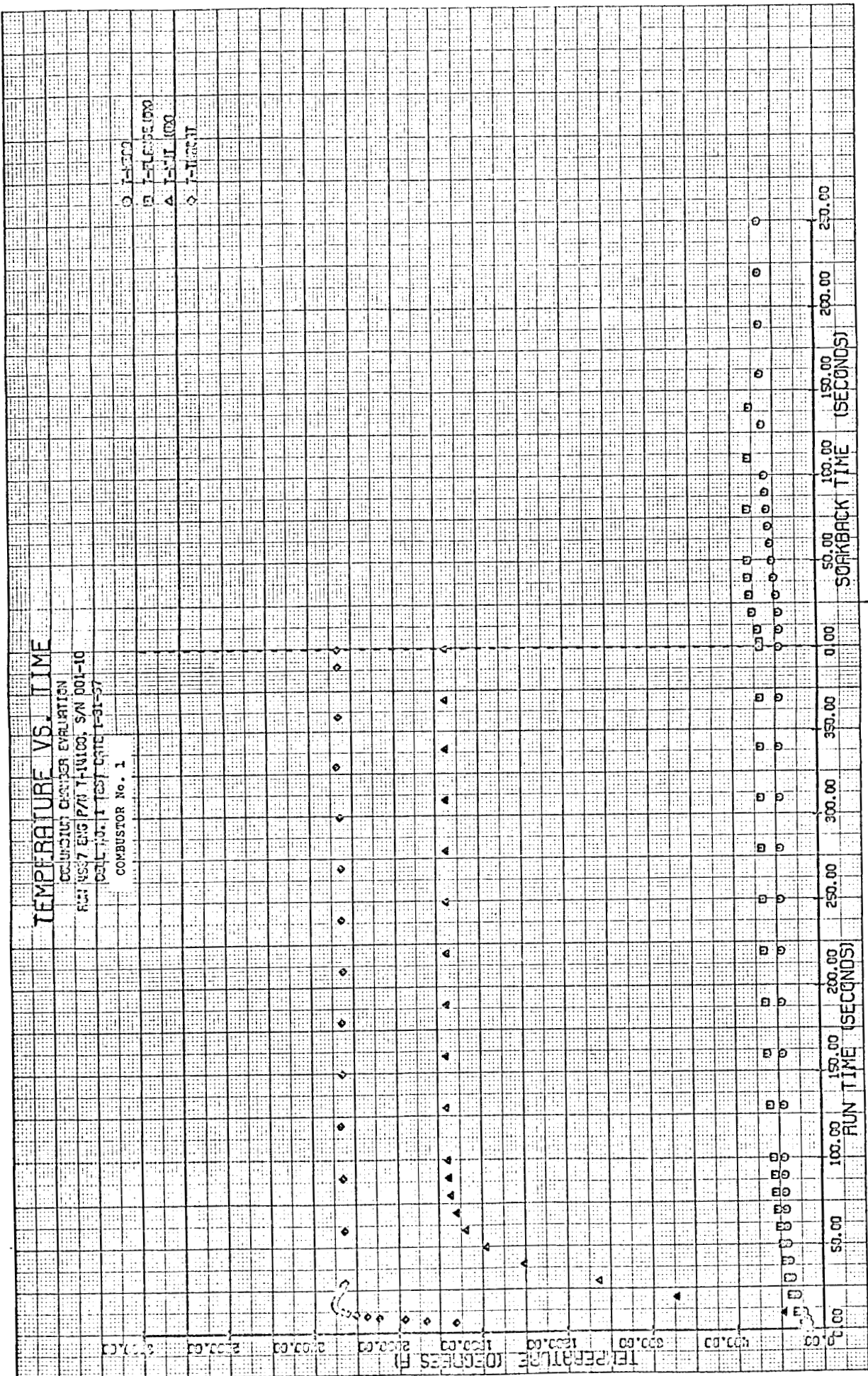
$$P_{m_0} = P_{m_f} = 170 \text{ PSIA}$$

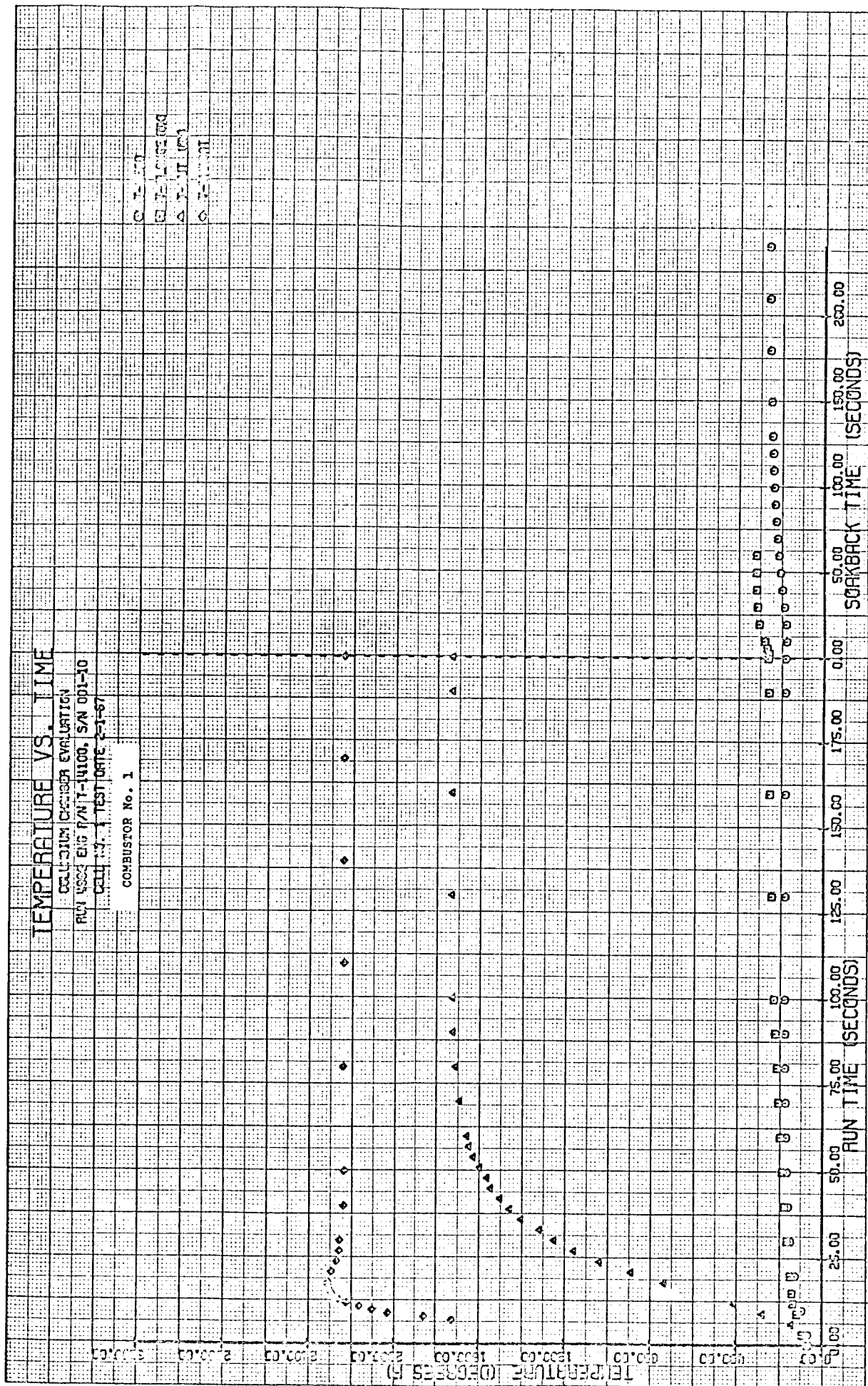
$$T_{fm_0} = T_{fm_f} = 75^{\circ}\text{F}$$

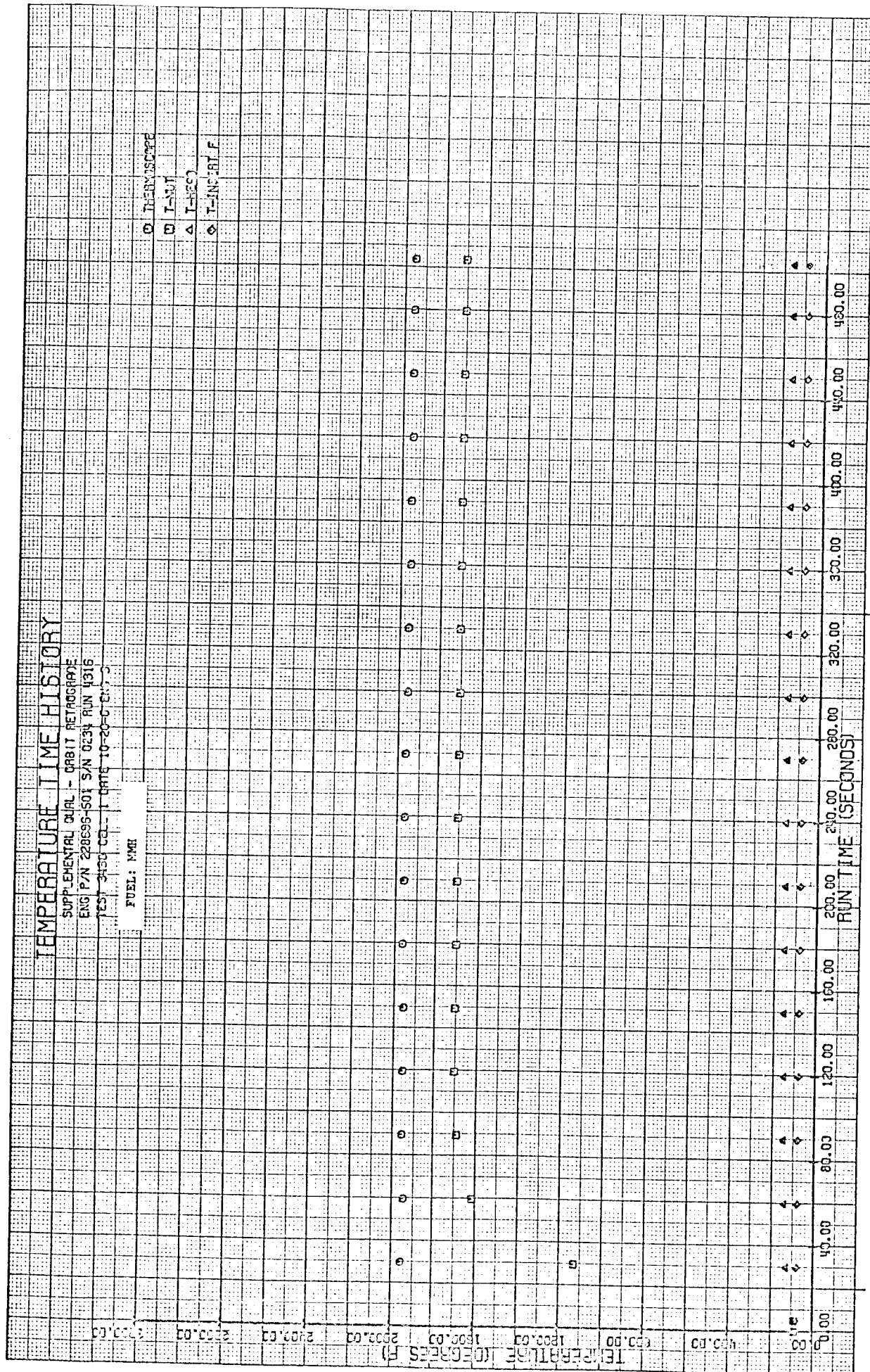
ENGINE ASSEMBLY 228687 S/N 0013 PAGE 5 OF 5
TEST NO. 3324 QUALIFICATION ENGINE # 4 TEST DATE 11/3/65
M.T.P. 0004A SEQUENCE # 17 APPENDIX PARAGRAPH I-5.1

TEST DATA	RUN NO. SG ₀	DATA STATION SG _f	P _{ch} TEST -PSIA	\dot{w}_f TEST -pps	\dot{w}_p TEST -pps	O/F TEST	I _{sp} VAC TEST -sec	C* TEST -ft/sec	ΔP_0 -psi	ΔP_f -psi
CORRECTED TO STD. COND.	O/F _s	I _{sp} VAC _s -sec	\dot{w}_f -pps	\dot{w}_o -pps	\dot{w}_p -pps	F _{VAC} -lbs	C* -ft/sec	P _{ch} -PSIA	C _f VAC _s	
	1356	480								
	1.4536	.9036	92.9	.1172	.3546	2.026	274.9	4985.	73.7	75.0
	2.038	275.7	.1177	.2400	.3577	98.6	4999.	94.0	1.774	
	1356	504								
	1.4536	.9036	92.9	.1172	.3542	2.022	274.4	4991.	73.6	74.6
	2.030	275.4	.1180	.2395	.3575	98.4	5009.	94.1	1.769	
	MEAN O/F _s		$\Delta O/F_s$	MEAN F _{VAC} - lbs.	ΔF_{VAC} - lbs.	MEAN I _{sp} VAC _s	$\Delta I_{sp}VACs$			









PAGE 2-17-67

TEMPERATURE VS. TIME
 QUALIFICATION ENGINE #4, ORBIT RETROGRADE TEST
 RUN #1356, CELL #1 TEST DATE: 11-3-65
 PROPELLANTS - A-30 & "BROWN" N_2O_4

0 F-4510
 0 F-4517
 A-F-4510/17

2-150

2-150

2-150

2-150

2-150

2-150

2-150

MAC 1328

C. Pulse Operation Survey Test Results

The purpose of the Pulse Operation Survey test was to demonstrate the thermal and structural integrity of the combustor when subjected to a large number of pulses with a variety of pulse mode duty cycles.

The test consisted of subjecting both combustors to 80 runs of 120 pulses (minimum) per run with electrical "on" times ranging from 0.010 second to 0.500 second, and electrical "off" times from 0.010 second to 0.300 second.

All runs of this test were successfully completed under the specified conditions without degrading the structural integrity of either combustor.

The Pulse Operation Survey test conducted with combustor No. 2 utilized N_2O_4 , per MSC-PPD-2A, as the oxidizer and MMH as the fuel. Both propellants were partially helium saturated per Section F, Method I. The propellants used for the Pulse Operation Survey test with combustor No. 1 were N_2O_4 , per MSC-PPD-2A and Aerozine-50; both propellants were fully helium saturated per the procedure shown in Section F, Method II of this report.

As specified in the test plan (Reference 1), the following pre-run conditions were required:

Fuel Inlet Temperature, T_{mf}	= $40 \pm 5^\circ F$
Oxidizer Inlet Temperature, T_{mo}	= $40 \pm 5^\circ F$
Fuel Inlet Pressure, P_{mf} (under flowing conditions)	= 170 ± 2.5 psia
Oxidizer Inlet Pressure, P_{mo} (under flowing conditions)	= 170 ± 2.5 psia
Head Temperature, T_{hd}	= $65^\circ F \begin{smallmatrix} +55 \\ -0 \end{smallmatrix}^\circ F$
Cell Pressure, P_{cell}	≤ 0.15 psia

Verification of the required temperatures and pressures for the tests conducted with combustor No. 2 and combustor No. 1 was obtained by data reduction as indicated in Figures 25 and 26 respectively. Since the fuel and oxidizer inlet pressures under steady state flowing conditions are not realized during short pulses, 5-second trim runs were used to establish

the required prerun pressures. These prerun pressures were 168 ± 2.5 psig for the oxidizer inlet and 161 ± 2.5 psig for the fuel inlet. Both are equivalent to a 170 ± 2.5 psia inlet pressure under steady state flowing conditions. All of the parameters were within the specified limits for the record pulse runs. On three trim runs, the head temperature was slightly below the required limit. The cell pressure was less than 0.15 psia prior to each run as verified by inspection stamping the engine log-books.

COLUMBIUM CHAMBER #2 PULSE OPERATION SURVEY
 ENGINE P/N T-14100, S/N 001-9, TEST #3448
 TEST DATE: 11-7-56, CELL #1, 27 VOLTS D.C.
 VERTICAL DOWN ORIENTATION, PROPELLANTS (FUEL-MEH) (OX.-N₂O₄ "GREEN")

INDICATES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS

RUE NUMBER	NUMBER PULSES	DUTY CYCLE "ON" TIME (sec)	DUTY CYCLE "OFF" TIME (sec)	PRE-RUN SET PRESSURES			PRE-RUN TEMPERATURES - °F		
				PNO	PNE	THF	TNO	THQ	TNO
4430	1 (Trim)	5		*	*	*	*	*	57
4431	1 (Trim)	5		*	*	*	*	*	*
4432	122	.010	.010	*	*	*	*	*	*
4433	122	.012	.010	*	*	*	*	*	*
4434	122	.015	.010	*	*	*	*	*	*
4435	122	.020	.010	*	*	*	*	*	*
4436	122	.035	.010	*	*	*	*	*	*
4437	122	.100	.010	*	*	*	*	*	*
4438	122	.230	.010	*	*	*	*	*	*
4439	122	.500	.010	*	*	*	*	*	*
4440	122	.010	.020	*	*	*	*	*	*
4441	122	.012	.020	*	*	*	*	*	*
4442	122	.015	.020	*	*	*	*	*	*
4443	122	.020	.020	*	*	*	*	*	*
4444	122	.035	.020	*	*	*	*	*	*
4445	122	.100	.020	*	*	*	*	*	*
4446	122	.230	.020	*	*	*	*	*	*
4447	122	.500	.020	*	*	*	*	*	*
4448	1 (Trim)	3		*	*	*	*	*	62
4449	122	.010	.040	*	*	*	*	*	*
4450	122	.012	.040	*	*	*	*	*	*
4451	122	.015	.040	*	*	*	*	*	*
4452	122	.020	.040	*	*	*	*	*	*
4453	122	.035	.040	*	*	*	*	*	*
4454	122	.100	.040	*	*	*	*	*	*
4455	122	.230	.040	*	*	*	*	*	*
4456	122	.500	.040	*	*	*	*	*	*
4457	122	.010	.060	*	*	*	*	*	*
4458	122	.012	.060	*	*	*	*	*	*
4459	122	.015	.060	*	*	*	*	*	*

COLUMBIUM CHAMBER #2 PULSE OPERATION SURVEY
 ENGINE P/N T-14100, S/N 001-9, TEST #3448
 TEST DATE: 11-7-66, CELL #1, 27 VOLTS D.C.
 VERTICAL DOWN ORIENTATION, PROPELLANTS (FUEL-MEH) (OX.-H₂O "GREEN")

*INDICATES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS

RUN NUMBER	NUMBER OF PULSES	DUTY CYCLE		PUL-RUN SET PRESSURES		PRE-RUN TEMPERATURES - °F		
		"ON" TIME (sec)	"OFF" TIME (sec)	PNO	PRF	TMT	TMO	THEAD
4460	122	.020	.060	*	*	*	*	*
4461	122	.035	.060	*	*	*	*	*
4462	122	.100	.060	*	*	*	*	*
4463	122	.230	.060	*	*	*	*	*
4464	122	.500	.060	*	*	*	*	*
4465	122	.010	.080	*	*	*	*	*
4466	122	.012	.080	*	*	*	*	*
4467	122	.015	.080	*	*	*	*	*
4468	122	.020	.080	*	*	*	*	*
4469	122	.035	.080	*	*	*	*	*
4470	122	.100	.080	*	*	*	*	*
4471	122	.230	.080	*	*	*	*	*
4472	122	.500	.080	*	*	*	*	*
4473	122	.010	.100	*	*	*	*	*
4474	122	.012	.100	*	*	*	*	*
4475	122	.015	.100	*	*	*	*	*
4476	122	.020	.100	*	*	*	*	*
4477	122	.035	.100	*	*	*	*	*
4478	122	.100	.100	*	*	*	*	*
4479	122	.230	.100	*	*	*	*	*
4480	122	.500	.100	*	*	*	*	*
4481	122	.010	.150	*	*	*	*	*
4482	122	.012	.150	*	*	*	*	*
4483	122	.015	.150	*	*	*	*	*
4484	122	.020	.150	*	*	*	*	*
4485	122	.035	.150	*	*	*	*	*
4486	122	.100	.150	*	*	*	*	*
4487	122	.230	.150	*	*	*	*	*
4488	122	.500	.150	*	*	*	*	*
4489	122	.010	.200	*	*	*	*	*

* INDICATES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS.

RUN NUMBER	NO. OF PULSES	DUTY CYCLE - SEC.		PRE-RUN SET PRESSURE		PRE-RUN TEMPERATURES - °F		
		"ON" TIME	"OFF" TIME	PMO	PRF	TRF	TMO	TEND
5000	1 (TRIM)	5.000		*	*	*	*	51
5001	120	0.010	0.010	*	*	*	*	*
5002	120	0.012	0.010	*	*	*	*	*
5003	120	0.015	0.010	*	*	*	*	*
5004	120	0.020	0.010	*	*	*	*	*
5005	120	0.035	0.010	*	*	*	*	*
5006	120	0.100	0.010	*	*	*	*	*
5007	120	0.230	0.010	*	*	*	*	*
5008	120	0.500	0.010	*	*	*	*	*
5009	120	0.010	0.020	*	*	*	*	*
5010	120	0.012	0.020	*	*	*	*	*
5011	120	0.015	0.020	*	*	*	*	*
5012	120	0.020	0.020	*	*	*	*	*
5013	120	0.035	0.020	*	*	*	*	*
5014	120	0.100	0.020	*	*	*	*	*
5015	120	0.230	0.020	*	*	*	*	*
5016	120	0.500	0.020	*	*	*	*	*
5017	1 (TRIM)	5.000		*	*	*	*	*
5018	120	0.010	0.040	*	*	*	*	*
5019	120	0.012	0.040	*	*	*	*	*
5020	120	0.015	0.040	*	*	*	*	*
5021	120	0.020	0.040	*	*	*	*	*
5022	120	0.035	0.040	*	*	*	*	*
5023	120	0.100	0.040	*	*	*	*	*

* INDICATES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS.

RUN NUMBER	NO. OF PULSES	DUTY CYCLE- SEC.		PRE-RUN SET PRESSURE			PRE-RUN TEMPERATURES - °F		
		"ON" TIME	"OFF" TIME	P40	P4F	PTF	T40	T4F	Thsed
5024	120	0.230	0.040	*	*	*	*	*	*
5025	120	0.500	0.040	*	*	*	*	*	*
5026	120	0.010	0.060	*	*	*	*	*	*
5027	120	0.012	0.060	*	*	*	*	*	*
5028	120	0.015	0.060	*	*	*	*	*	*
5029	120	0.020	0.060	*	*	*	*	*	*
5030	120	0.035	0.060	*	*	*	*	*	*
5031	120	0.100	0.060	*	*	*	*	*	*
5032	120	0.230	0.060	*	*	*	*	*	*
5033	120	0.500	0.060	*	*	*	*	*	*
5034	120	0.010	0.080	*	*	*	*	*	*
5035	120	0.012	0.080	*	*	*	*	*	*
5036	120	0.015	0.080	*	*	*	*	*	*
5037	120	0.020	0.080	*	*	*	*	*	*
5038	120	0.035	0.080	*	*	*	*	*	*
5039	120	0.100	0.080	*	*	*	*	*	*
5040	120	0.230	0.080	*	*	*	*	*	*
5041	120	0.500	0.080	*	*	*	*	*	*
5042	120	0.010	0.100	*	*	*	*	*	*
5043	120	0.012	0.100	*	*	*	*	*	*
5044	120	0.015	0.100	*	*	*	*	*	*
5045	120	0.020	0.100	*	*	*	*	*	*
5046	120	0.035	0.100	*	*	*	*	*	*
5047	120	0.100	0.100	*	*	*	*	*	*

* INDICATES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS.

RUN NUMBER	NO. OF PULSES	DUTY CYCLE - SEC.		PRE-RUN SET PRESSURE		PRE-RUN TEMPERATURES - °F		
		"ON" TIME	"OFF" TIME	PMO	FMF	TAF	TMO	TMO-A
5048	120	0.230	0.100	*	*	*	*	*
5049	120	0.500	0.100	*	*	*	*	*
5050	1 (TRIM)	5.000		*	*	*	*	*
5051	122	0.010	0.150	*	*	*	*	*
5052	122	0.012	0.150	*	*	*	*	*
5053	122	0.015	0.150	*	*	*	*	*
5054	122	0.020	0.150	*	*	*	*	*
5055	122	0.035	0.150	*	*	*	*	*
5056	122	0.100	0.150	*	*	*	*	*
5057	122	0.230	0.150	*	*	*	*	*
5058	122	0.500	0.150	*	*	*	*	*
5059	122	0.010	0.200	*	*	*	*	*
5060	122	0.012	0.200	*	*	*	*	*
5061	122	0.015	0.200	*	*	*	*	*
5062	122	0.020	0.200	*	*	*	*	*
5063	122	0.035	0.200	*	*	*	*	*
5064	122	0.100	0.200	*	*	*	*	*
5065	122	0.230	0.200	*	*	*	*	*
5066	122	0.500	0.200	*	*	*	*	*
5067	122	0.010	0.250	*	*	*	*	*
5068	122	0.012	0.250	*	*	*	*	*
5069	122	0.015	0.250	*	*	*	*	*
5070	122	0.020	0.250	*	*	*	*	*
5071	122	0.035	0.250	*	*	*	*	*

PULSE OPERATION SURVEY (COMBUSTOR No. 1)

ENGINE P/N T-14100, S/N 001-10, TEST # 3448

PAGE 4 OF 4

TEST DATE: 2-2-67, CELL # 1, 27 VOLTS D.C.

* INDICATES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS.

[illegible]

D. Ignition Test Results

The purpose of this test was to demonstrate the structural integrity of the combustor and the adequacy of the injector-combustor seal design when the engine is operated at environmental temperatures equal to the minimum safe temperatures of the S/M RCS engines.

Both engines were subjected to 90 runs of from 4 to 9 pulses per run. All valve electrical ON times were 0.012 second, whereas the electrical OFF times varied from 0.100 second to 1.500 seconds. All but the last pulse of each run had a normal 2 ms mechanical fuel lead; the last pulse had either a zero, 6 or 15 ms mechanical oxidizer lead, as prescribed in the test plan (Reference 1). All runs were conducted with the engine in the vertical-up firing position.

As verified by post test inspections, both engines satisfactorily completed all runs at the conditions required without exhibiting any degradation of structural integrity.

Nitrogen tetroxide, per MSC-PPD-2A, and MMH were the propellants used for the ignition testing of combustor No. 2 (Engine P/N T-14100, S/N 0001-8), whereas the ignition test with combustor No. 1 (Engine P/N T-14100, S/N 0001-11) utilized the same oxidizer, but incorporated Aerozine-50 as the fuel. The propellants were fully helium saturated, per Section F, Method II, for the testing of both combustors.

The following prerun limits were specified by the test plan:

Fuel Inlet Pressure, P_{mf}	= 172 ± 2 psia
Oxidizer Inlet Pressure, P_{mo}	= 172 ± 2 psia
Fuel Valve Inlet Temperature, T_{mf}	= $40 \pm 5^{\circ}\text{F}$
Oxidizer Valve Inlet Temperature, T_{mo}	= $40 \pm 5^{\circ}\text{F}$
Head Temperature, T_{hd}	$\geq 40^{\circ}\text{F}$
Combustor Flange Temperature, T_{chl}	= $40 \pm 5^{\circ}\text{F}$
Bell Nut Temperature, T_{nut}	= $0 \pm 5^{\circ}\text{F}$
Cell Pressure, P_{cell}	≤ 0.001 psia

As shown in Figures 27 and 28, the prerun temperatures for the ignition runs with combustors No. 2 and No. 1, respectively, were within the specified range. The head temperature prior to run No. 24 with combustor No. 2 (Engine S/N 0001-8) was 1°F below the specified range, and the test

run was repeated. The cell pressure was less than 0.001 psia, and the oxidizer and fuel inlet pressures were 172 ± 2 psia prior to all runs as verified by inspection stamping the respective engine logbooks.

Two accelerometers, oriented in the manner shown in Figure 29, were mounted on both of the participating engines to obtain an indication of ignition characteristics. As yet, no reliable correlation between acceleration data and chamber overpressure has been made. The data acquired is therefore primarily qualitative and is presented for completeness of documentation. The maximum acceleration recorded during each run with combustor No. 2 (Engine P/N T-14100, S/N 0001-8) is tabulated in Figure 27. Also tabulated in this figure are the ignition delay, pulse number at which peak acceleration occurred and other data associated with the maximum "G" load. Figure 28 presents the maximum accelerations measured during each run with combustor No. 1 (Engine P/N T-14100, S/N 0001-11). Due to electronic saturation of the amplifier used to drive the oscillograph galvanometers, the ignition delay and other time dependent data associated with maximum acceleration were not reducible.

COLLISION CHAMBER IGNITION OVERPRESSURE TEST
ELLIS P/N T-14100, S/N 0001-8, TEST # 3448
TEST DATE: 11-2-66, CELL # RRL "G", 27 VOLTS D.C.
VERTICAL UP ORIENTATION, PROPELLANTS: (FUEL-ME) ($\text{OX-H}_2\text{O}$ "GREEN")
COMBUSTOR NO. 2

** DENOTES RUNS WHERE AX AND AY DIDN'T RESPOND ON O'GRAPH
* INDICATES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS.

RUN NUMBER	NUMBER OF PULSES IN DUTY CYCLE	IGNITION DELAY OF PEAK AX M.S.	OX LEAD OF PEAK AX (MECH) M.S.	"OFF" TIME PRIOR TO PEAK AX SEC.	PULSE OF PEAK AX	PEAK AX G's	PEAK AX G's	PRERUN TEMPERATURES °F				
								T _{ad}	T _{wt}	T _{ch₁}	T _{co}	T _{mf}
19	4	**	**	**	**	406	364	*	*	*	*	*
20	4	**	**	**	**	305	834	*	*	*	*	*
21	7	**	**	**	**	156	784	*	*	*	*	*
22	7	**	**	**	**	455	964	*	*	*	*	*
23	9	**	**	**	**	206	784	*	*	*	*	*
24	9	**	**	**	**	405	1733	*	*	*	*	*
25	9	**	**	**	**	335	1384	39	*	*	*	*
26	4	8.7	-2	540.	1	236	1883	*	*	*	*	*
27	4	7.7	-2	300.	1	325	1483	*	*	*	*	*
28	7	7.5	-2	420.	1	206	584	*	*	*	*	*
29	7	7.5	-2	300.	1	485	934	*	*	*	*	*
30	9	6.9	-2	0.350	4	385	804	*	*	*	*	*
31	9	7.5	-2	0.350	3	405	1134	*	*	*	*	*
32	4	7.4	-2	360.	1	355	1283	*	*	*	*	*
33	4	7.9	-2	0.600	2	405	1313	*	*	*	*	*
34	7	7.5	-2	0.600	3	385	1104	*	*	*	*	*
35	9	7.5	-2	480.	1	755	1283	*	*	*	*	*
36	9	7.5	-2	0.600	3	305	1034	*	*	*	*	*
37	4	7.4	-2	300.	1	305	1154	*	*	*	*	*
38	4	7.9	-2	360.	1	305	2103	*	*	*	*	*
39	4	7.6	-2	1.000	2	305	1833	*	*	*	*	*
40	7	7.6	-2	540.	1	256	1583	*	*	*	*	*
41	9	8.0	-2	1.000	4	485	1983	*	*	*	*	*
42	9	7.5	-2	1.000	4	405	1104	*	*	*	*	*
43	4	7.5	-2	1.500	2	405	884	*	*	*	*	*
44	4	7.5	-2	360.	2	405	904	*	*	*	*	*
45	4	7.4	-2	360.	1	455	1283	*	*	*	*	*
46	7	7.5	-2	1.500	1	585	1083	*	*	*	*	*
47	7	8.0	0	1.500	7	585	1903	*	*	*	*	*
48	9	7.5	0	360.	9	286	1114	*	*	*	*	*
49	9	7.5	-2	360.	1			*	*	*	*	*

COLUMBIA CHAMBER IGNITION OVERPRESSURE TEST
ENGINE P/N T-14100, S/N 0001-8, TEST # 3448
TEST DATE: 11-2-66, CELL # RRL "G", 27 VOLTS D.C.
VERTICAL UP ORIENTATION, PROPELLANTS: (FUEL-AE) (OX-L₂O₄ "GREEN")
COMBUSTOR NO. 2

** DEMOTES RUNS WHERE AX AND AY DIDN'T RESPOND ON O'GRAPH
* INDICATES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS.

RUN NUMBER	NUMBER OF PULSES IN DUTY CYCLE	IGNITION DELAY OF PEAK AX M.S.	OX LEAD OF PEAK AX (MSEC) M.S.	"OFF" TIME PRIOR TO PEAK AX SEC.	PULSE OF PEAK AX	PEAK AX G's	PEAK AY G's	PRESSURE TEMPERATURES °F				
								Tot	Taut	Tch ₁	Tmo	Tmf
50	4	3.0	6	0.100	4	505	1663	*	*	*	*	*
51	4	2.5	6	0.100	4	854	1763	*	*	*	*	*
52	7	2.8	6	0.100	7	305	2083	*	*	*	*	*
53	7	5.5	6	0.100	7	954	2303	*	*	*	*	*
54	9	4.8	-2	0.100	7	635	2763	*	*	*	*	*
55	9	8.0	-2	240.	1	705	1783	*	*	*	*	*
56	4	7.6	-2	360.	1	205	884	*	*	*	*	*
57	4	5.5	6	0.350	4	954	2993	*	*	*	*	*
58	7	5.2	6	0.350	7	505	2903	*	*	*	*	*
59	7	5.5	6	0.350	7	555	2003	*	*	*	*	*
60	9	4.5	6	0.350	9	455	2013	*	*	*	*	*
61	9	6.5	-2	0.350	3	355	734	*	*	*	*	*
62	4	5.5	6	0.600	4	655	2493	*	*	*	*	*
63	4	5.2	6	0.600	4	854	2323	*	*	*	*	*
64	7	5.5	6	0.600	7	625	3570	*	*	*	*	*
65	7	5.7	6	0.600	7	1034	3482	*	*	*	*	*
66	9	7.5	-2	0.600	3	705	784	*	*	*	*	*
67	9	7.3	-2	0.600	3	405	1084	*	*	*	*	*
68	4	7.5	-2	1.000	2	305	714	*	*	*	*	*
69	4	7.5	-2	1.000	2	156	1333	*	*	*	*	*
70	7	8.0	-2	1.000	5	555	704	*	*	*	*	*
71	7	7.0	-2	1.000	4	605	874	*	*	*	*	*
72	9	7.0	-2	1.000	6	785	2963	*	*	*	*	*
73	9	8.0	-2	1.000	7	785	3282	*	*	*	*	*
74	4	7.0	-2	1.500	3	385	934	*	*	*	*	*
75	4	8.0	-2	1.500	3	156	1064	*	*	*	*	*
76	7	7.5	-2	1.500	6	304	2063	*	*	*	*	*
77	7	7.0	-2	1.500	4	305	1463	*	*	*	*	*
78	9	7.5	-2	1.500	8	455	1233	*	*	*	*	*
79	9	7.5	-2	1.500	3	205	1063	*	*	*	*	*

COLLECTION CHAMBER IGNITION OVERPRESSURE TEST
ENGINE P/N T-14100, S/N 0001-8, TEST # 3448
TEST DATE: 11-2-66, CELL # RRL "G", 27 VOLTS D.C.
VERTICAL UP ORIENTATION, PROPELLANTS: (FUEL-MEH) (OX-L₂O, "GREEN")
COMBUSTOR NO. 2

** DENOTES RUNS WHERE AX AND AY DIDN'T RESPOND ON O'GRAPH
* INDICATES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS.

RUN NUMBER	NUMBER OF PULSES IN DUTY CYCLE	IGNITION DELAY OF PEAK AX M.S.	OX LEAD OF PEAK AX (PCTCH) M.S.	"CTF" TICS PRIOR TO PEAK AX SEC.	PULSE OF PEAK AX	PEAK AX G's	PEAK AY G's	PRESSURE TEMPERATURES °F				
								Tot	Tot	Tch ₁	Tch ₂	Tch ₃
80	4	7.5	-2	0.100	2	206	484	*	*	*	*	*
81	4	**	**	**	**	186	384	*	*	*	*	*
82	7	**	**	**	**	355	334	*	*	*	*	*
83	7	**	**	**	**	405	684	*	*	*	*	*
84	9	7.0	-2	300.	1	156	884	*	*	*	*	*
85	9	**	**	**	**	505	1074	*	*	*	*	*
86	4	**	**	**	**	305	684	*	*	*	*	*
87	7	7.0	-2	0.350	2	156	884	*	*	*	*	*
88	7	6.5	-2	0.350	5	904	1633	*	*	*	*	*
89	7	6.5	-2	0.350	4	705	864	*	*	*	*	*
90	9	**	**	**	**	824	1063	*	*	*	*	*
91	9	6.5	-2	0.350	5	455	1483	*	*	*	*	*
92	4	7.0	-2	0.600	2	385	1333	*	*	*	*	*
93	4	7.0	-2	0.600	3	286	1263	*	*	*	*	*
94	7	7.5	-2	0.600	2	325	564	*	*	*	*	*
95	7	8.0	-2	300.	1	226	234	*	*	*	*	*
96	9	7.5	-2	0.600	4	685	884	*	*	*	*	*
97	9	7.5	-2	0.600	2	535	1184	*	*	*	*	*
98	4	8.0	-2	1.000	2	854	1114	*	*	*	*	*
99	4	8.0	-2	300.	1	286	1363	*	*	*	*	*
100	7	8.0	-2	1.000	4	266	764	*	*	*	*	*
101	7	8.0	-2	1.000	6	505	1134	*	*	*	*	*
102	9	8.0	-2	1.000	3	705	934	*	*	*	*	*
103	9	7.5	-2	1.000	2	505	1313	*	*	*	*	*
104	4	7.5	-2	1.500	3	335	685	*	*	*	*	*
105	4	7.5	-2	1.500	2	565	934	*	*	*	*	*
106	7	8.0	-2	1.500	6	655	1083	*	*	*	*	*
107	7	8.0	-2	1.500	6	305	884	*	*	*	*	*
108	9	7.5	-2	1.500	5	745	934	*	*	*	*	*
109	9	8.0	-2	1.500	7	854	1163	*	*	*	*	*

COLUMBIUM ALLOY COMBUSTION CHAMBER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS
IGNITION C/EPRESSURE TEST

ENGINE P/N T-14100, S/N 001-11, TEST # 3448

TEST DATE: 2-8-67, CELL RRL "G", 27 VOLTS D.C.

VERTICAL UP ORIENTATION, PROPELLANTS: (FUEL- A-50) (OX- N2O4 "GREEN")

* DENOTES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS. (COMBUSTOR No. 1.)

RUN NUMBER	NUMBER OF PULSES IN DUTY CYCLE	PEAK AX G's	PEAK AY G's	PRE-RUN TEMPERATURES ~ °F				
				T _{td}	T _{mt}	T _{ch 1}	T _{co}	T _{mf}
4	4	113	241	*	*	*	*	*
5	4	381	461	*	*	*	*	*
6	7	14	750	*	*	*	*	*
7	7	123	581	*	*	*	*	*
8	9	14	231	*	*	*	*	*
9	9	322	571	*	*	*	*	*
10	4	829	2068	*	*	*	*	*
11	4	620	1329	*	*	*	*	*
12	7	322	2188	*	*	*	*	*
13	7	491	2357	*	*	*	*	*
14	9	710	2767	*	*	*	*	*
15	9	600	3845	*	*	*	*	*
16	4	521	1060	*	*	*	*	*
17	4	879	2138	*	*	*	*	*
18	7	252	2028	*	*	*	*	*
19	7	322	1988	*	*	*	*	*
20	9	521	1808	*	*	*	*	*
21	9	43	181	*	*	*	*	*
22	4	481	1070	*	*	*	*	*
23	4	282	1369	*	*	*	*	*
24	7	480	3316	*	*	*	*	*
25	7	809	2926	*	*	*	*	*
26	9	411	980	*	*	*	*	*
27	9	640	1020	*	*	*	*	*
28	4	441	1160	*	*	*	*	*
29	4	988	1459	*	*	*	*	*
30	7	282	1629	*	*	*	*	*
31	7	262	1130	*	*	*	*	*

COLLURIUM ALLOY COMBUSTION CHAMBER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS
IGNITION CATERPRESSURE TEST

ENGINE P/N T-14100, S/N 001-11, TEST # 3448

TEST DATE: 2-8-67, CELL RRL "G", 27 VOLTS D.C.

VERTICAL UP ORIENTATION, PROPELLANTS: (FUEL- A-50) (OX- M204 "GREEN")

(COMBUSTOR No.1)

* DENOTES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS.

RUN NUMBER	NUMBER OF PULSES IN DUTY CYCLE	PEAK AX G's	PEAK AY G's	PRE-RUN TEMPERATURES °F				
				T _{td}	T _{ht}	T _{ch 1}	T _{co}	T _{tf}
32	9	551	1130	*	*	*	*	*
33	9	411	990	*	*	*	*	*
34	4	14	21	*	*	*	*	*
35	4	570	521	*	*	*	*	*
36	7	202	81	*	*	*	*	*
37	7	779	1110	*	*	*	*	*
38	9	33	171	*	*	*	*	*
39	9	33	111	*	*	*	*	*
40	4	541	2377	*	*	*	*	*
41	4	0	41	*	*	*	*	*
42	7	560	3905	*	*	*	*	*
43	7	411	1459	*	*	*	*	*
44	9	381	860	*	*	*	*	*
45	9	1068	2268	*	*	*	*	*
46	4	33	81	*	*	*	*	*
47	4	521	2258	*	*	*	*	*
48	7	541	1249	*	*	*	*	*
49	7	859	2268	*	*	*	*	*
50	9	113	1219	*	*	*	*	*
51	9	153	1189	*	*	*	*	*
52	4	24	41	*	*	*	*	*
53	4	332	1978	*	*	*	*	*
54	7	620	1369	*	*	*	*	*
55	7	332	1569	*	*	*	*	*
56	9	948	2457	*	*	*	*	*
57	9	1445	3326	*	*	*	*	*
58	4	322	1639	*	*	*	*	*
59	4	471	940	*	*	*	*	*

COLEBURN ALLOY COMBUSTION CHAMBER DEVELOPMENT PROGRAM-PRELIMINARY DESIGN CHAMBER TESTS
IGNITION OVERPRESSURE TEST

ENGINE P/N T-14100, S/N 001-11, TEST # 3448

TEST DATE: 2-8-67, CELL RRL "C", 27 VOLTS D.C.

VERTICAL UP ORIENTATION, PROPELLANTS: (FUEL- A-50) (OX- N2O4 "GREEN")

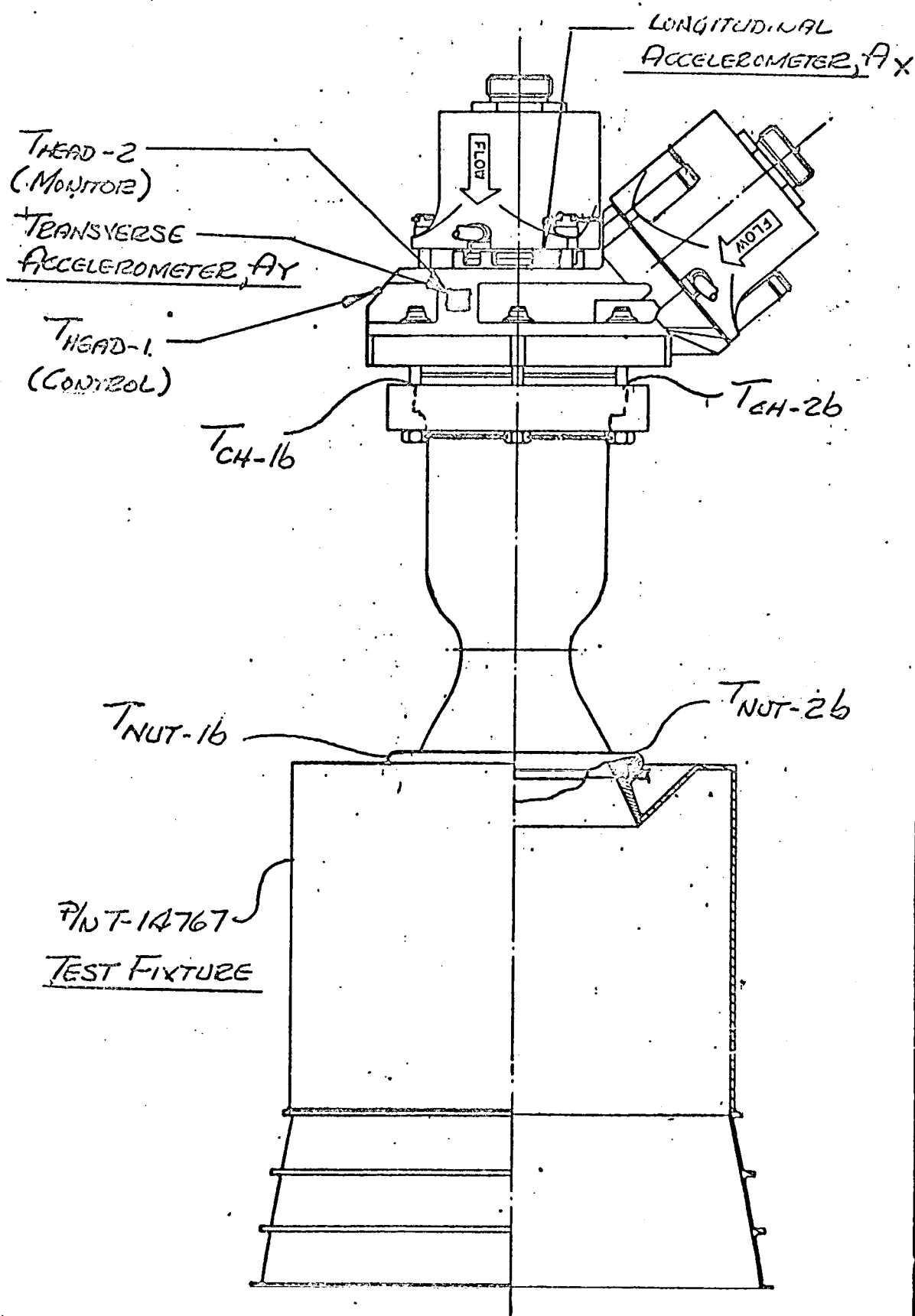
(COMBUSTOR No. 1)

* DENOTES DATA POINTS THAT ARE WITHIN TEST PLAN LIMITS.

RUN NUMBER	NUMBER OF PULSES IN DUTY CYCLE	PEAK AX G's	PEAK AY G's	PRE-RUN TEMPERATURES °F				
				T _{hd}	T _{hut}	T _{ch 1}	T _{ch 2}	T _{thf}
60	7	978	2357	*	*	*	*	*
61	7	401	1709	*	*	*	*	*
62	9	1316	2228	*	*	*	*	*
63	9	1187	1519	*	*	*	*	*
64	4	73	1170	*	*	*	*	*
65	4	0	81	*	*	*	*	*
66	7	292	391	*	*	*	*	*
67	7	113	71	*	*	*	*	*
68	9	33	511	*	*	*	*	*
69	9	153	461	*	*	*	*	*
70	4	14	71	*	*	*	*	*
71	4	779	8048	*	*	*	*	*
72	7	1177	2397	*	*	*	*	*
73	7	372	1319	*	*	*	*	*
74	9	193	411	*	*	*	*	*
75	9	362	2128	*	*	*	*	*
76	4	14	71	*	*	*	*	*
77	4	302	810	*	*	*	*	*
78	7	968	3985	*	*	*	*	*
79	7	1038	2078	*	*	*	*	*
80	9	1038	2677	*	*	*	*	*
81	9	302	1719	*	*	*	*	*
82	4	421	920	*	*	*	*	*
83	4	391	1469	*	*	*	*	*
84	7	670	1000	*	*	*	*	*
85	7	650	2058	*	*	*	*	*
86	9	411	760	*	*	*	*	*
87	9	421	2098	*	*	*	*	*

THERMOCOUPLE AND ACCELEROMETER SCHEMATIC

IGNITION TEST



E. Post Test Combustor Checks

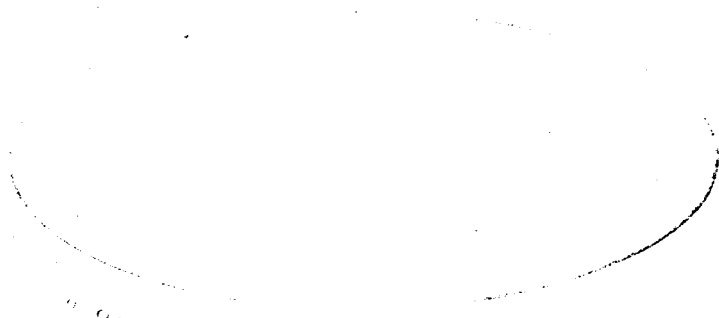
The purpose of these checks was to verify that the structural integrity of the combustor was not degraded as a result of combustion testing.

A visual inspection, combustor-injector seal leak check and combustor O.D. measurements were made post test.

Combustors No. 1 and No. 2 were not damaged or deformed as a result of combustion testing.

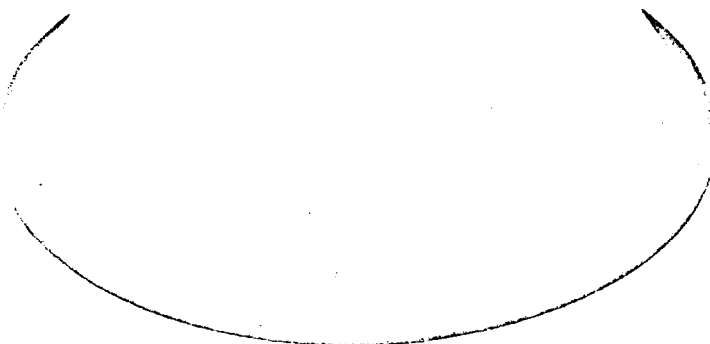
Visual inspection of the combustors at their respective post test disassemblies reveals no material or coating degradation.

Post test photographs of combustors No. 2 and No. 1 are presented in Figures 30 and 31, respectively. The post combustion test combustor-injector head seal leakage rate of combustors No. 2 and No. 1 was 2.0 psi per 5 minutes and 2.5 psi per 5 minutes, respectively. These values were verified by TMC inspection stamp in the engine logbook. These leakage rate values represent the total decrease in lockup pressure (dry, filtered GN₂ originally at 175 psi) over a time period of 5 minutes. The Apollo S/M RCS combustor-injector allowable leakage rate is 15 psi per 6 minutes. Presented in Figures 32 and 33 are the pretest and post test outside diameter dimensions of combustors No. 2 and No. 1, respectively. As shown, neither combustor was deformed as a result of testing.



0002

TEST 3448 228949 S/N 002 - C103 COMBUSTOR
ATL-PAD G AFTER TEST - SIDE VIEW (u)
18 NOV 66

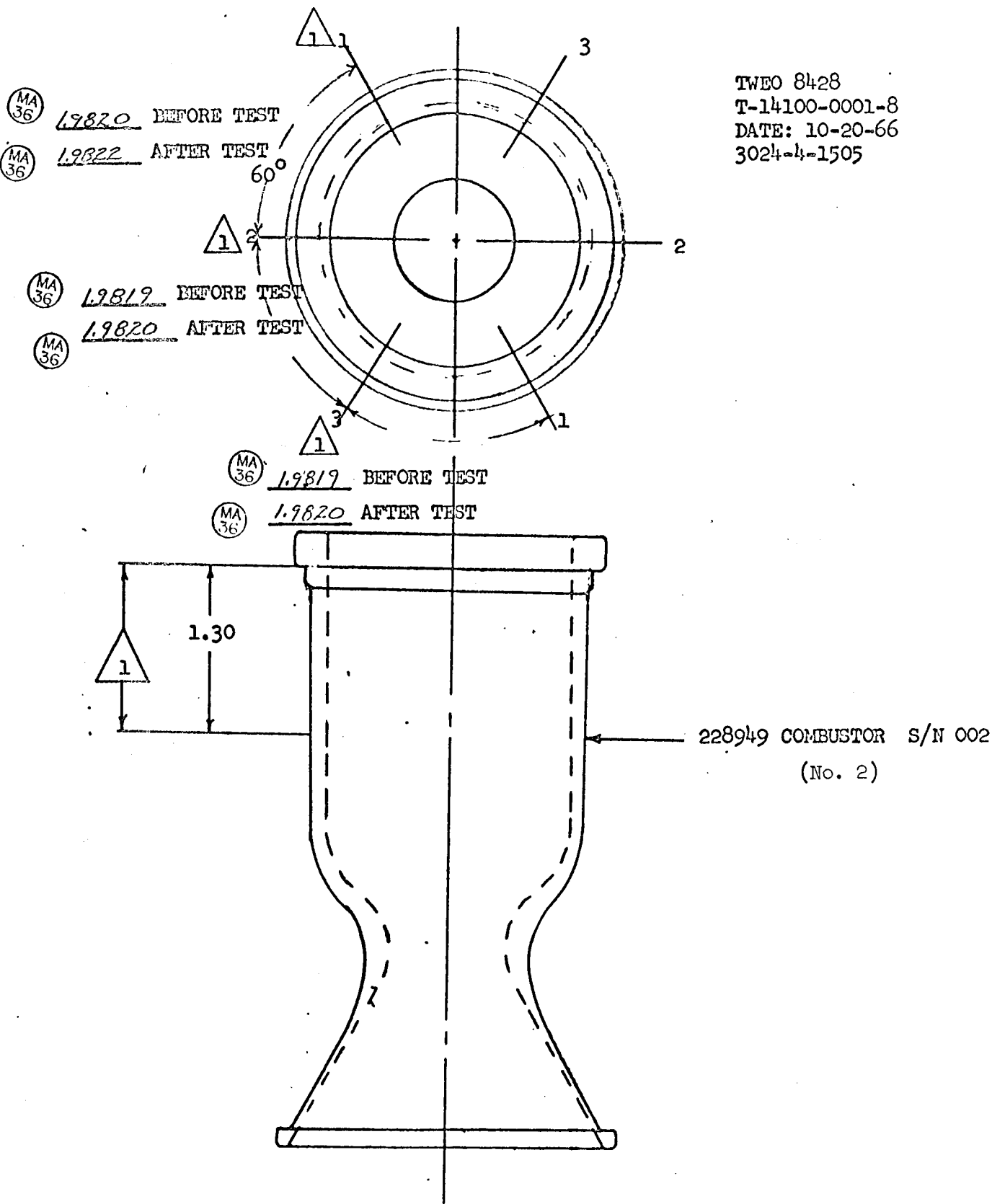


NEG. T3448-4

NEG. 8459-10

P/N 228949 S/N 003 COLUMBIUM CHAMBER - C103 ALLOY
SYLCOR R512A COATING--AFTER TEST
13 FEB 67
(u)

COLUMBIUM COMBUSTOR PRE AND POST TEST O.D. MEASUREMENTS



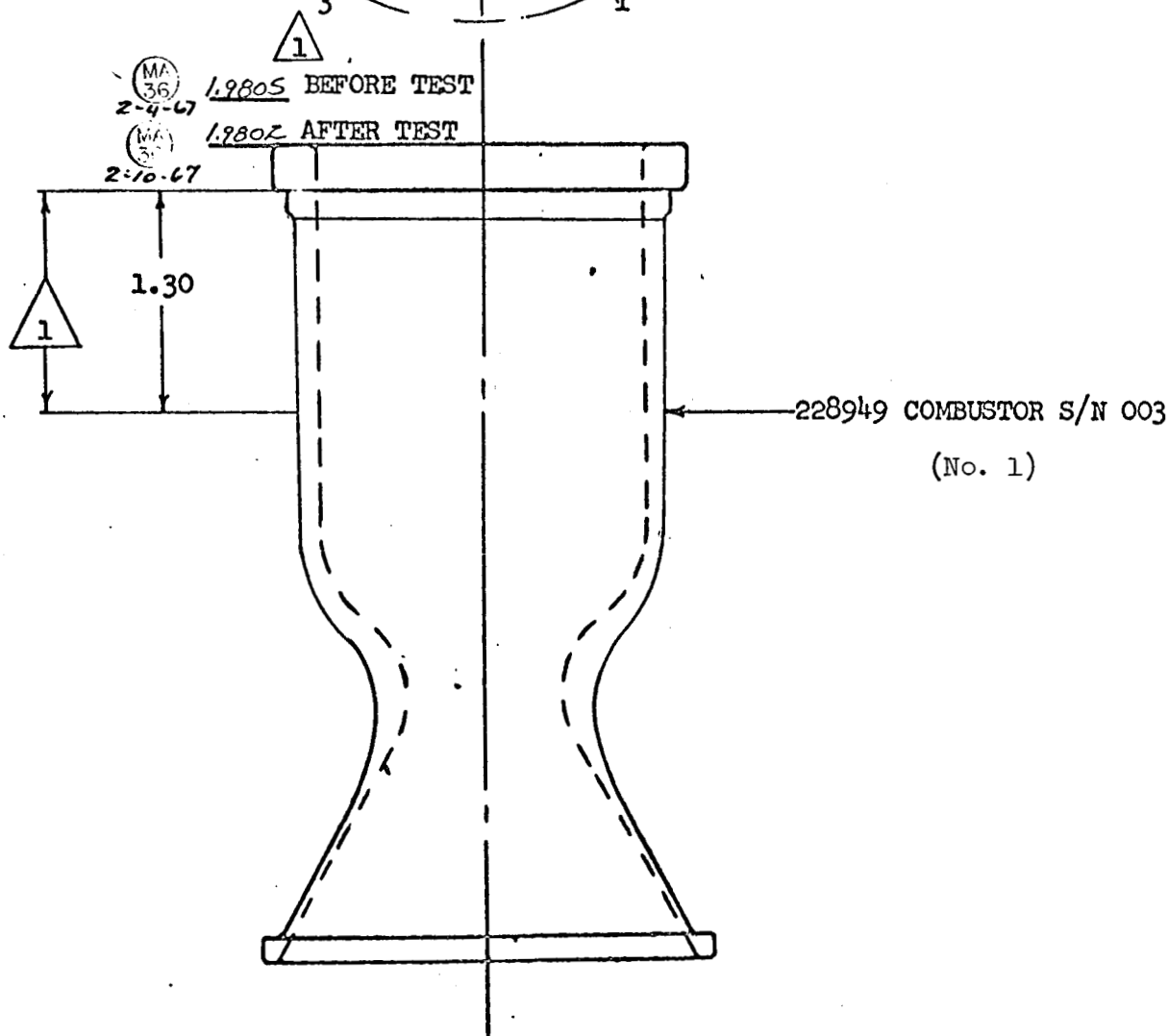
PLEASE PERFORM AN INSPECTION OF THE COMBUSTOR O.D. AT THE THREE (3) LOCATIONS INDICATED. RECORD THE ACTUAL DIMENSIONS IN THE LOG BOOK THE FOURTH PLACE. (.XXX) DIMENSION NO. 2 IS TO BE TAKEN IN LINE WITH THERMOCOUPLE HOLES.

COLUMBIUM COMBUSTOR PRE AND POST TEST O.D. MEASUREMENTS

TWEO 9166
T-14100-0001-10
DATE: 2-4-67
3024-4-1505

MA 36 1.9810 BEFORE TEST
2-4-67
MA 36 1.9815 AFTER TEST
2-10-67

MA 36 1.9805 BEFORE TEST
2-4-67
MA 36 1.9800 AFTER TEST
2-10-67



PLEASE PERFORM AN INSPECTION OF THE COMBUSTOR O.D. AT THE THREE (3) LOCATIONS INDICATED. RECORD THE ACTUAL DIMENSIONS IN THE LOG BOOK THE FOURTH PLACE. (.XXXX) DIMENSION NO. 2 IS TO BE TAKEN IN LINE WITH THERMOCOUPLE HOLES.

F. Propellant Helium Saturation Methods

1. Method I - Partial Saturation

The propellants were partially helium saturated by pressurizing the main storage or pulse tank, whichever was applicable, for a minimum of 24 hours at run pressure (~ 185 psia) and temperature (ambient or $40 \pm 5^\circ\text{F}$, as applicable) before the test.

2. Method II - Complete Saturation

The propellants were helium saturated by stirring while at run pressure (172 ± 3 psia) and temperature ($40 \pm 5^\circ\text{F}$) for a minimum of four hours in the case of the oxidizer, and one hour for the fuel prior to test. This procedure was shown during the Apollo development program to result in essentially complete saturation.

V CONCLUSIONS
VI RECOMMENDATIONS

V. CONCLUSIONS

On the basis of the data acquired from the Preliminary Design Colum-bium Combustor Test, it was concluded that the thermal characteristics of the columbium combustor and associated attach hardware are compatible with the Apollo S/M RCS engine and Apollo mission requirements, that the mechanical design of the combustor and associated attach hardware is compatible with the Apollo S/M RCS engine, that the structural integrity of the combustor material/coating system is adequate for Apollo S/M RCS engine applications, and that the use of the columbium combustor and associated attach hardware in no way degrades engine performance.

VI. RECOMMENDATIONS

It is recommended that the preliminary design columbium combustor (P/N 228949), combustor-head interface seal (P/N 228948) and attach ring (P/N 228947) be accepted without modification as the final configuration.

APPENDIX I

INVERTED ENGINE INJECTOR HEAD DETONATION ANALYSIS

Introduction

The Preliminary Design Columbiu Combustor Test (Ignition Test) commenced on 18 October 1966 with Engine P/N T-14200, S/N 0001-12 which incorporated combustor No. 2. The Ignition Test was stopped after 14 runs because an explosion in the oxidizer manifold damaged the oxidizer standoff and valve seat. The columbiu combustor and associated attach hardware were not damaged by the detonation. After assessment of the incident, the preliminary design test was started over with Engine P/N T-14100, S/N 0001-8, which incorporated combustor No. 2. As a result of the investigation, subsequent tests were conducted with a bell nut temperature of zero \pm 5°F and a head temperature of 40°F or greater.

The explosion occurred on the first pulse of the fourteenth run. The previous run had consisted of nine pulses; 12 ms on and 350 ms off. The time interval between the thirteenth and fourteenth runs was 17 minutes at a cell pressure of about 13 microns (15×10^{-3} mm Hg). The injector head temperature and combustor flange temperature were 14°F and 19°F, respectively, at the time of the detonation. The propellants utilized were MMH and nitric oxide inhibited N₂O₄. The propellant temperatures were 40 \pm 5°F. The engine was oriented vertically up. Figure I-1 summarizes the run data. An analytical study was conducted to determine the mechanism that produced the manifold detonation. The results of that analysis are presented herein.

Summary of Proposed Mechanism

The investigation discussed below shows that the following sequence of events, which is strongly dependent upon engine temperature, offers a plausible mechanism for the observed explosion.

During each pulse, fuel is sprayed on the wall from the fuel coolant holes. This amounts to about 3.6×10^{-4} pounds for each 12-millisecond pulse.

During the interval between pulses, a portion of the fuel evaporates. This leaves part of the fuel still on the wall. Almost none of the fuel in the fuel manifold evaporates. Most of the oxidizer leaves the oxidizer manifold during the off time. The chamber pressure created by the evaporating oxidizer suppresses the evaporation of the fuel from the walls.

After the pulse train ends, there is about 3×10^{-3} pounds of fuel on the wall. The fuel manifold contains an additional 1.5×10^{-3} pounds.

The fuel on the wall drains down toward the face of the injector. At the same time, it is vaporizing and flowing out of the exit nozzle. The drainage rate is much faster than the evaporation rate, so that within one second most of the fuel on the wall forms a puddle on the injector face.

The fuel on the injector face flows into the oxidizer manifold injector holes. Capillary action assists in draining the fuel into the holes. The flow rate through the holes is comparable to the drainage rate. Capillary forces are not sufficient to prevent flow through the holes.

The oxidizer manifold substantially fills with fuel before the evaporation from the face eliminates the puddle.

Re-evaporation of the MMH from the oxidizer manifold is a very slow and poorly understood process. It is limited by heat flow into the thermal standoff. If the fuel evaporates through the injector holes at the head temperature, it would take about six minutes. The thermal mass of the bottom of the standoff can provide the required heat, but this would cause an 89°F drop in temperature. If the flow rate is limited by heat flow through the liquid, the evaporation time would be over 100 minutes. The emptying may involve two-phase flow through the injector holes. This would increase the emptying rate by some presently unknown amount. Emptying of the fuel manifold occurs more rapidly than emptying of the oxidizer manifold because of the better heat supply there. While the fuel manifold is emptying, evaporation out of the oxidizer manifold will be suppressed.

All the processes described above depend on the temperature of the head and walls of the engine. At higher wall temperatures, the fuel on the walls will evaporate more rapidly between pulses. At higher head temperatures, the vapor pressure of the fuel inside the oxidizer manifold will prevent some of the liquid in the puddle from entering that cavity. At a sufficiently high temperature, the problem should disappear because none of the fuel on the face of the injector can accumulate in the oxidizer manifold.

Analytical Studies

Each of the items noted in the Summary of Proposed Mechanism was the subject of an analytical investigation. Most of the results depend on more basic analyses conducted previously.

A. Fuel Spray on Wall

Approximately 25 percent of the fuel flow occurs through the wall coolant holes in the injector. The nominal fuel flow is approximately 0.12 pound per second. If the manifold is full at the start of the pulse, then

$$\begin{aligned} w_p &= f \dot{w} t && \text{- fuel on wall for one pulse} \\ f &= 25 \text{ percent} && \text{- fraction sprayed on wall} \\ \dot{w} &= 0.12 \text{ lb/sec.} && \text{- nominal fuel flow rate} \\ t &= 12 \text{ milliseconds} && \text{- pulse duration for run 13} \\ w_p &= 3.6 \times 10^{-4} \text{ lb.} \end{aligned}$$

This creates a film on the wall approximately 1×10^{-3} inch thick over 10 in^2 surface area.

B. Evaporation between Pulses

Significant fuel evaporation does not take place until the oxidizer manifold has emptied. While this process is only partially understood, it appears that the time to empty the oxidizer manifold at 20°F head temperature is at least 300 milliseconds. Thus, very little fuel will evaporate for 350 milliseconds off time. The fuel evaporation rate at 15°F wall temperature is about 10^{-3} lb/second for 1 mil thickness.

C. Total Wall Fuel

The maximum amount of fuel which could remain on the wall is the amount per pulse multiplied by the number of pulses. Some of this evaporates during a run, and some of it may react with the shutdown oxidizer. Cold flow movies show that very little fuel flows out of the injector during the first pulse. In a string with off times shorter than 350 milliseconds, the fuel manifold will be full when the valve first opens for each of the subsequent pulses.

$$\begin{aligned} w_{\text{tot}} &= (n - 1) w_p && \text{- total accumulation on wall} \\ n &= 3 && \text{- number of pulses} \\ w_p &= 3.6 \times 10^{-4} \text{ lb.} && \text{- wall spray per pulse} \\ w_{\text{tot}} &= 2.9 \times 10^{-3} \text{ lb.} \end{aligned}$$

This fuel forms a film with a thickness of approximately 9×10^{-3} inches.

D. Wall Drainage and Evaporation

The fuel on the walls drains down towards the face of the injector. An analysis of the drainage rate for MMH shows that 70 percent of fuel will reach the face of the injector within one second. The fraction drained versus time is shown in Figure I-2.

Evaporation from the wall occurs simultaneously with the drainage. The rate of evaporation for a 20°F wall is shown in Figure I-3.

The time to evaporate 3×10^{-3} lb. will be on the order of 10 seconds or more. Drainage is clearly the phenomenon with the highest rate, hence the fuel on the walls will form a puddle on the injector face.

-E. Flow into the Manifold

The fuel on the dish-shaped face of the injector will cover the injector holes. The liquid will flow into the holes if the fluid wets the interior surface. Since MMH apparently wets most metals, the holes will fill. The fluid will flow through the holes into the manifold if the pressure differential plus gravity force is sufficient to overcome the capillary force holding the liquid in the hole. A puddle of 3×10^{-4} lb. of MMH covering 1 in² of surface will have a depth of approximately 0.10 inch. The geometry at the end of the hole inside the manifold tends to reduce the capillary forces, hence the estimate given below is conservative.

Flow will occur if

$$\frac{2\sigma}{r} < \rho g(h + t) + P_{ch} - P_m$$

Using:

- σ = 37 dynes/cm - surface tension coefficient for MMH
- r = 0.0017 inch - radius of the oxidizer injector holes
- ρ = 0.902 gm/cm³ - density of MMH
- h = 0.2 inch - depth of oxidizer injector holes
- t = 0.1 inch - depth of puddle over holes

we find that the capillary forces will be overcome and flow into the manifold will occur if:

$$P_{ch} - P_m > 0.015 \text{ psi}$$

The initial pressure in the chamber and manifold will be about 0.0202 psia when the 10 mil thick wall film is evaporating. As the film drains, the chamber pressure will increase, reaching 0.067 psi in approximately 0.3 second when the wall film has thinned down to about 1 mil. During this drainage, a transient pressure gradient will arise between the chamber and the manifold of more than the 0.015 psi necessary to initiate flow.

The flow into the oxidizer manifold will continue until either the driving pressure differential disappears or the manifold fills. At an internal manifold temperature of 8°F, the internal pressure would reach 0.077 psia. This would be sufficient to stop the flow. For lower manifold temperatures, the flow would continue.

The cooling of the oxidizer manifold due to evaporation of the oxidizer after shutdown should provide more than enough cooling to reach this temperature. Temperature drops of this magnitude are observed for engines firing downward, where much less manifold cooling occurs.

The rate of flow from the puddle into the manifold depends on the pressure differential. At 0.049 psi differential plus the gravity head, the flow rate will be:

$$\begin{aligned}\dot{W} &= C_D \times A \times \sqrt{2 g \rho \Delta P} \\ &= 0.6 \times 0.00792 \sqrt{2 \times 386 \times 0.0326 \times 0.049} \\ &= 0.0052 \text{ lb/second}\end{aligned}$$

Therefore, the entire manifold could be filled with 1.3×10^{-3} pounds of fuel in 0.25 second. Hence, there will be ample time to fill the manifold.

F. Evaporation from the Face

The MMH in the puddle will not evaporate significantly while the drainage is occurring because of the higher pressures in the chamber created by the fuel on the wall. After the drainage has occurred, there will be about as much fuel remaining on the face as there is in the oxidizer manifold, 1.3×10^{-3} pounds of MMH. The evaporation time of this material from a 1 in² puddle can be estimated using the rate for a 10 mil film. (Free convection stirs the liquid below the film surface.) The rate is about 10^{-4} lb/second, so that at least 13 seconds will be required to evaporate. This allows ample time to fill the oxidizer manifold with fuel.

G. Re-evaporation from the Oxidizer Manifold

If the oxidizer manifold can fill with MMH as hypothesized above, it would take a very long time to empty it by evaporation alone. The surface area between the preigniter tube and the outer wall is:

$$A_S = 0.0427 \text{ in}$$

The total hole area is:

$$A_H = 0.00941 \text{ in}$$

and therefore,

$$A_H/A_S = 0.22$$

At 20°F, the evaporation rate would be

$$\dot{w}_{mo} = 2 \times 10^{-7} \text{ lb/second}$$

The time to empty would be 103 minutes. This time increases to 190 minutes at 10°F.

The liquid column in the manifold may not be stable, however. At 8°F, the vapor pressure is:

$$P_v = 0.077 \text{ psia}$$

The gravity head of a 1-inch column of fluid is only:

$$\begin{aligned} P_g &= \rho gh \\ &= 0.032 \text{ psia} \end{aligned}$$

The pressure could force the fluid out of the manifold after the chamber pressure drops below 0.045 psia if nucleation of vapor bubbles can occur. At -12°F, the vapor pressure would be 0.032 psia, and the liquid could not be forced out under any conditions.

At some sufficiently high temperature, the liquid would undoubtedly be sprayed out by vaporization at the bottom of the manifold. High speed movies indicate that this may not occur for temperatures less than 20°F for MMH. The mechanics of manifold emptying facing upward is not known well enough to yield a final resolution of this issue.

Conclusions

It seems clear that the explosion under investigation could have been due to the drainage of MMH into the oxidizer manifold after the previous run. The MMH can build up on the wall during a succession of pulses, because the wall temperature and head temperature are too low to permit evaporation of the propellants during the 350 millisecond off time. The accumulated liquid can drain from the walls and cover the oxidizer injector holes with fuel. As the fuel drains, transient pressure differentials are set up which will force the fuel puddled on the face into the oxidizer manifold. This is only possible when the manifold temperature is below about 8°F. The mechanism of emptying the fuel from the oxidizer manifold is not fully understood. If evaporation alone is involved, it could take over 100 minutes. Boiling in the manifold would increase the emptying rate. High speed movies of chamber emptying suggest that boiling will not occur at head temperatures below 20°F.

All of the steps in this process are temperature dependent. At a sufficiently high temperature, there will be no accumulation. At some other temperature, liquid which accumulates and drains cannot flow into the oxidizer manifold.

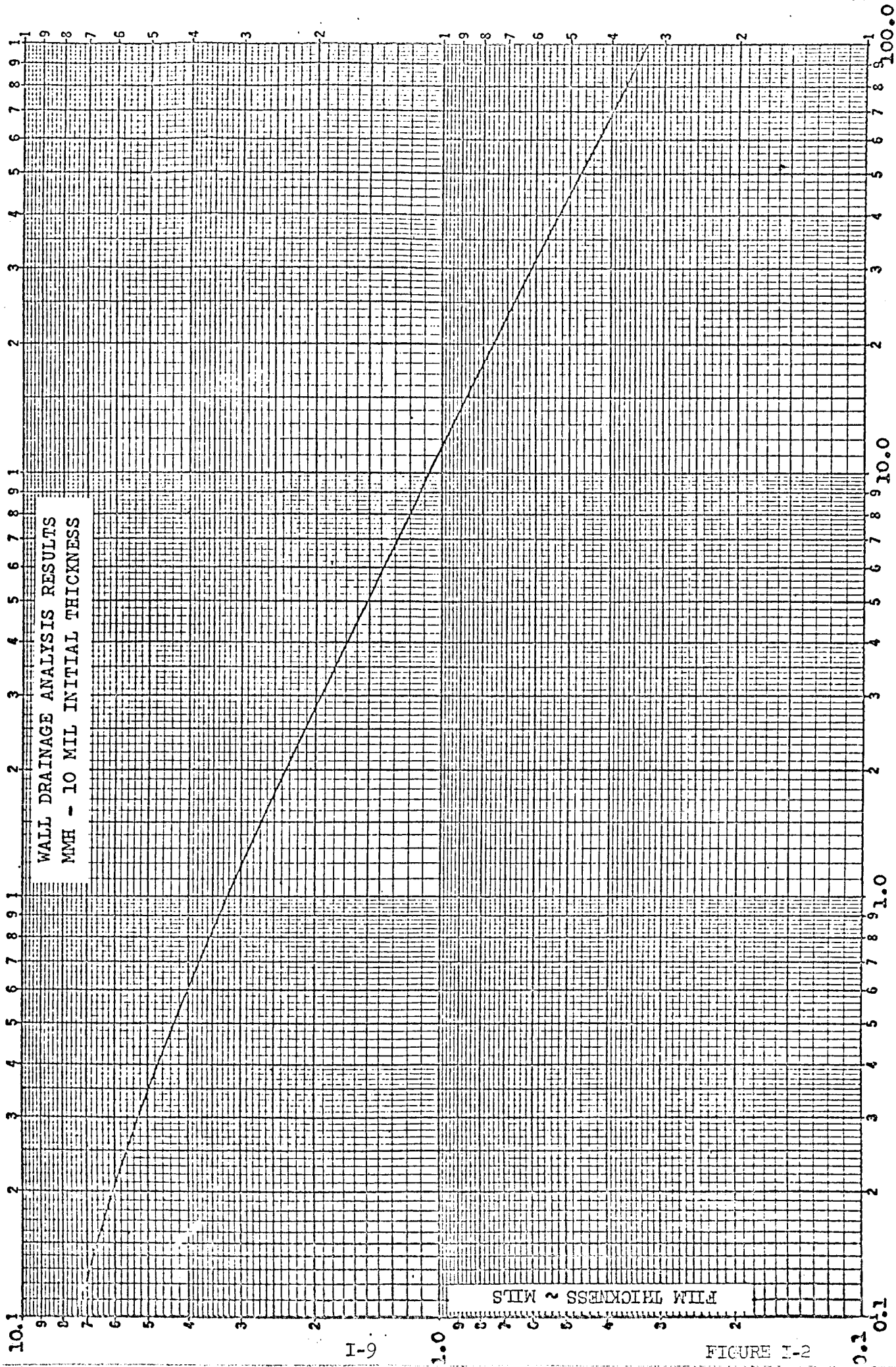
The incidence of explosion in inverted engines can be reduced by increasing the temperature of the engine hardware. This conclusion is borne out by an examination of conditions under which explosions have previously occurred. The bulk of such explosions occurred at head temperatures below 40°F.

PRELIMINARY DESIGN COMBUSTOR IGNITION TEST DATA

ENGINE P/N T-14200, S/N 0001-12

COMBUSTOR NO. 2

Run	No. of Pulses	On (ms)	Off (ms)	Temperatures ~ °F			Time to Next Run (min)	Acceleration G max.
				T _{nut}	T _{ch}	T _{head}		
1	15	50	62	90	100	100	44	
2	4	12	100	-16	23	28	13	< 500
3	4	12	100	-16	23	28	6	<1100
4	7	12	100	-19	20 ± 5	30	6	740
5	7	12	100	-19	20 ± 5	30	8	800
6	9	12	100	-17	20 ± 5	22	9	1700
7	9	12	100	4-18	20 ± 5	25	6	970
8	4	12	350	-18	20 ± 5	25	4	1600
9	4	12	350	-19	20 ± 5	23	6	1170
10	7	12	350	-19	20 ± 5	22	5	1400
11	7	12	350	-17	20 ± 5	21	8	930
12	9	12	350	-17	20 ± 5	20	6	570
13	9	12	350	-18	20 ± 5	19	17	720
14	4	12	600	-15	{15 14} two readings	18.5		9070 1st pulse

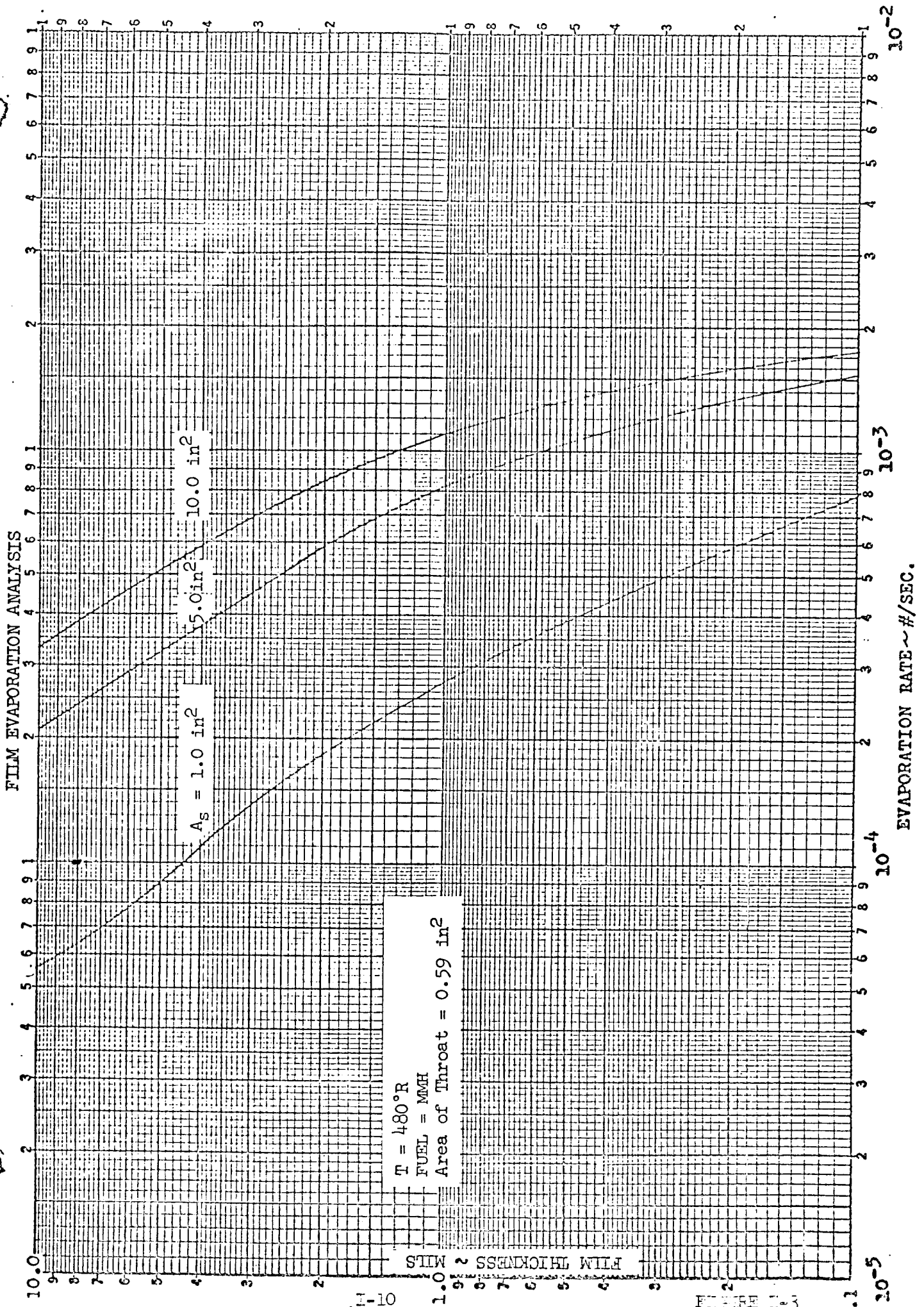


DRAINAGE TIME ~ SECONDS

FIGURE I-2

I-9

FILM EVAPORATION ANALYSIS



$T = 480^\circ R$
 FUEL = MMH
 Area of Throat = 0.59 in^2